Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2009

Introduction

The Water & Environmental Research Institute of the Western Pacific or WERI is one of 54 similar water research institutes set up by U.S. Congressional legislation at each Land Grant University in the United States and in several territories. The Institute is now in its 35th year of operation.

WERI's mission is to seek solutions through research, teaching and outreach programs, to issues and problems associated with the location, production, distribution, and management of freshwater resources. The Institute provides its regional stakeholders with technical expertise in a diversity of water resources related fields including tropical climatology, surface water hydrology, rainfall catchment systems, groundwater modeling and management, water distribution systems, soil erosion and mitigation strategies and various aspects of water quality. Faculty members contribute significantly to both undergraduate and graduate teaching programs at the University of Guam (UOG) and conduct vigorous research aimed at improving economic conditions and the quality of life for citizens of Guam and the regional island nations. WERI also operates a state of the technology water analytical laboratory and geographical information systems analysis and training facility.

WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the Institute was created specifically to administer Department of Interior funds (via the US Geological Survey) under Section 104-B of the Water Resources Research Act. WERI has responsibility for the administration of three 104-B base grants: one for Guam, one for the Commonwealth of the Northern Mariana Islands (CNMI), and one for the Federated States of Micronesia (FSM). This report summarizes the Institute's regional activities under the USGS 104-B base grant program for the period March 1, 2009 to February 28, 2010 (FY'09).

Currently WERI has a fulltime director who is also a UOG faculty member, five (5) regular and one (1) emeritus research faculty, a water analysis laboratory manager and technician, a GIS and network administrator, two office staff, as well as six (6) graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program

During FY09, WERI faculty were involved as principal investigators on sixteen (16) research and training projects. Funding sources for these projects, in addition to the US Geological Survey, included the National Oceanic and Atmospheric Administration, the US Weather Service and the US Environmental Protection Agency, local agencies such as the Guam Bureau of Statistics and Plans, the Guam Environmental Protection Agency, and direct appropriations from the Guam Legislature.

Over the same time frame, WERI faculty and staff taught thirteen (13) graduate courses and five (5) undergraduate courses in the Environmental Science MS program and the undergraduate Pre-Engineering curriculums respectively. At the same time WERI faculty were first or second authors on seventeen (17) refereed journal articles and conference proceedings, ten (10) technical reports and newsletters, twelve (12) professional presentations, and three (3) workshops. WERI faculty members served on twenty one (21) thesis committees of students in the Environmental Science and Biology MS programs and chaired eleven (11) of them.

Following is a list of non USGS Funded Projects carried out by the Institute during the 2009-2010 reporting period:

DIRECT LOCAL FUNDING: Guam Hydrologic Survey • Northern Guam Aquifer Recharge • Guam Geologic Map Update and Revision • Reconstructing the Climate History of Guam • Temporal and Spatial Variations in Guam's Groundwater Quality Water Resources Monitoring Program • In Cooperation with

Hawaii District, USGS

GUAM BUREAU OF STATISTICS AND PLANS: • Watershed Management GIS Scholarship for Student in Environmental Science MS Program

GUAM ENVIRONMENTAL PROTECTION AGECY (GEPA) & USPA: • Precision Mapping of Isohyets in Target Storms over the Northern Guam Lens Aquifer • Applicability of US EPA's New Groundwater Under the Direct Influence (GWUDI) of Surface Water Ruling to Guam's Karst Limestone Aquifer

NATIONAL SCIENCE FOUNDATION: • Paleoclimate study of West Pacific Warm Pool from Guam's Speleothems

NATIONAL WEATHER SERVICE: • U.S. Department of Commerce/NOAA Project • Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Climate Forecast & Information • Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Development of an Extended and Long-Range Precipitation System over the Pacific Islands

SAIPAN COMMONWEALTH UTILITIES COMMISSION (CUC), GWA & GEPA: • Training of GWA, GEPA and CUC Engineers and Private Consultants in use of the MWHSOFT Water Distribution System Modeling Program

OTHERS: • EarthTech Environmental Consultants: Review of Water Utility Study to Support EIS MC Relocation from Okinawa, Japan to Guam • AECOM Environmental Consultants: Review of Water Utility Study to Support EIS MC Relocation from Okinawa, Japan to Guam

Research Program Introduction

The Water and Environmental Research Institute (WERI) Advisory Council is the body that determines research goals and priorities for WERI in general and the USGS 104B program in particular. The Research Advisory Council (RAC) for Guam consists of representatives from all Guam governmental agencies involved with water resources development or regulation, members of U.S. Federal agencies, military organizations on Guam that deal with water resources issues and members of the university research community. The RAC for the Commonwealth of the Northern Mariana Islands (CNMI) and the Federated States of Micronesia (FSM) consist of representatives from various government departments that deal with water resources, representatives from the local colleges, private sector engineers, environmentalists, and planners, and University of Guam research faculty.

WERI held RAC meetings in September through October 2009. Nineteen (19) people attended the Guam meeting, twenty four (24) attended the CNMI meeting and sixteen (16) the FSM meeting. The meetings provided a scientific forum for information exchange on new and recently completed projects within each regional entity. Each RAC group examined the research education and training priorities identified in past years and added or amended where appropriate.

In early November, a Request for Proposals (RFP) letter was sent out by e-mail to over three hundred (300) regional representatives in Guam, the CNMI and FSM (Figure 1). Recipients included all past and present RAC members; faculty members at the University of Guam, the Northern Marianas College in Saipan and the College of Micronesia in Pohnpei, and water resource professionals from several government agencies. Accompanying the RFP message were: a) a blank proposal form for submittal on the USGS Web Site, b) detailed instructions on how to fill out the form, and c) the critical water resource research, education and training needs identified for Guam, the CNMI and FSM.

Seven (7) research proposals, four (4) for Guam, two (2) for the CNMI and one (1) for the FSM; two (2) environmental educational programs, one for Guam and one for the CNMI, and two (2) information transfer and training programs for the FSM were submitted for consideration in response to the RFP. Three review panels, each composed of three highly regarded water resources professionals and RAC members were established to evaluate the research proposals. Their task was to evaluate and score the proposals relevant to their particular region in accordance with the long-standing criteria listed in the RFP. The appropriate proposals were e-mailed separately to the members of each review panel along with the critical needs list and a scoring form. They were advised to work independently and given two weeks to submit their numerical assessments to the WERI Director. Their scores were then tabulated and the projects ranked in descending order of average score. Projects approved for funding were selected based on their regional ranking and availability of funds.

Baseline Study of Coastal Discharge of Groundwater on Guam

Basic Information

Title:	Baseline Study of Coastal Discharge of Groundwater on Guam
Project Number:	2008GU165B
Start Date:	2/27/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrogeochemistry, Hydrology
Descriptors:	Groundwater Discharge, Groundwater Quality, Groundwater Nutrient Concentrations
Principal Investigators:	John Jenson

Publication

1. Charette, Matthew. A., Paul B. Henderson, Crystalline F. Breier, Meagan E. Gonneea, John W. Jenson, and Jorge Herrera-Silveira, 2010, Submarine Groundwater Discharge from Karst Systems: Is Radium Tracing the Fresh Component? Workshop: Radium and Radon Isotopes as Environmental Tracers, Institute for Advanced Studies, Hebrew University of Jerusalem, March 14-19, 2010.

PROJECT SYNOPSIS REPORT

Project Title: Baseline Study of Coastal Discharge of Groundwater on Guam

Problem and Research Objectives

The Guam Water Resources Advisory Council has identified "*Baseline studies to help identify the locations and levels of key contaminants impacting Guam's ground and surface resources, and the processes that might explain their presence,*" as one of its research priorities under "*Ground, surface, and coastal waters*." We still know very little about how the total volume of aquifer discharge is distributed across the coastal zone or how much the flux may vary over time at any given discharge point in response to storms or seasonal variations in rainfall. We also lack baseline data on the concentrations of nutrients or toxins that may come from any given discharge feature and how concentrations might vary with seasonal or other changes in rainfall intensity. This project is helping to provide new and heretofore unattainable baseline information on the mass flux distribution and concentrations of nitrogen in the groundwater that discharges into the coastal waters surrounding the limestone plateau of northern Guam. This information is needed by managers and regulators of Guam's fresh water and coastal resources, including the Guam Waterworks Authority, Guam Environmental Protection Agency, and Department of Aquatic and Wildlife Resources.

Methodology

To evaluate the current and future impact of coastal groundwater discharge-derived nutrient flow on the coastal marine ecosystem, we are examining the natural abundance stable nitrogen isotopic signature of marine biota, which will provide a basis for constructing nitrogen loading models that might be applied to other Pacific Island marine ecosystems.

Principal Findings and Significance

This projects constitutes a baseline study to identify and provide insight into the source *locations and levels of a key contaminant, nitrogen, impacting Guam's groundwater*, and the processes that might explain its presence. It will also provide some *new insight into the effect of nitrogen nutrient loading on the coastal ecosystem.*

Calibration and Application of LUOM (Luo, 2007) in Southern Guam Watersheds With and Without Flow Data

Basic Information

Title:	Calibration and Application of LUOM (Luo, 2007) in Southern Guam Watersheds With and Without Flow Data
Project Number:	2009GU153B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Category:	Models, Surface Water, Hydrology
Descriptors:	Numerical model, LUOM, distributed watershed modeling
Principal Investigators:	Charles Luo, Shahram Khosrowpanah

Publications

1. Luo, Q. Charles and Shahram Khosrowpanah, 2009, Developing the LUOM in southern Guam watersheds without flow data, in Proceedings of AWRA 2009 Annual Water Resources Conference Nov. 9-12, 2009, Seattle, Washington.
2. Luo, Q. Charles and Shahram Khosrowpanah, 2010, Calibration and Application of LUOM in Southern Guam Watersheds With and Without Flow Data, Water and Environmental Research Institute of the Western Pacific (WERI), University of Guam, Mangilao, Guam, 93pp.

PROJECT SYNOPSIS REPORT

Project Title: Calibration and Application of LUOM (Luo, 2007) in Southern Guam Watersheds With and Without Flow Data

Problems and Research Objectives

In southern Guam, there are a few watersheds that have both rainfall and streamflow data. But some other watersheds have only rainfall data but no streamflow data. In the watersheds without streamflow data, it is obviously difficult to carry out watershed management studies which require streamflow data. Meanwhile, there are two problems with most of the watersheds with streamflow data. One is that the streamflow gage is not always located at the watershed outlet but a distance upstream of the outlet. The other is that there are many missing data in the streamflow data. These problems also induce difficulties to the watershed management and plans.

The objective of this study was to calibrate and validate the LUOM (Luo, 2007) in the southern Guam watersheds in which there are both rainfall and streamflow data, and then to apply the calibrated model to the southern Guam watersheds which have a and have no streamflow gage to generate long term time series of streamflow for the whole watershed. As the result, this project developed the methodology to generate long term time series of streamflow for watersheds without a streamflow gage.

Methodology

The Large-scale, Unified and Optimization Model, LUOM (Luo, 2007) is a fully physically based, two-dimensional distributed watershed model simulating the hydrologic cycle on a watershed scale. The model discretizes the watershed into rectangular grid cells and makes use of spatial distributed GIS (Geographic Information Systems) data such as DEM (Digital Elevation Model), vegetation, and soil data. The model comprises of a series of sub-models for climate data distribution, evapotranspiration, infiltration, groundwater, surface flow, etc. The surface flow sub-model solves the two-dimensional shallow water equations using the diffusive wave approximation. With the input of climate data, mainly precipitation, temperature and wind speed, the model is able to generate not only one-dimensional output – discharge hydrographs, but also two-dimensional hydrologic quantities such as evapotranspiration, infiltration, soil moisture, groundwater table and surface water depth. Simulation of the impacts of land use (vegetation) transformation and global climate changes is within the model's capability.

The diffusive wave approximation of the two-dimensional free surface shallow water flow equations are employed as the governing equations for the surface flows including both overland and channel flows. The diffusive wave model is able to simulate backwater phenomenon, in which the water may flow from the downstream reaches or the estuary back to the upstream reaches in a river. The model is also able to simulate the flows on the overland areas with a zero slope. In this model, both overland and channel flows are placed in the same physical domain, in which a channel grid cell exchanges mass and momentum with the eight adjacent grid cells of overland, channels and water bodies. The finite difference method based on the staggered grid scheme, in which the vectors of velocity are defined at the borders of the grid cell and the water depth is defined at the center of the grid cell, is utilized to discretize the governing equations and

the optimization numerical scheme, SIMPLE, is employed to solve the finite difference equations using a tri-diagonal matrix.

The surface flow model is coupled with models for evapotranspiration, infiltration and groundwater recharge, water exchanges between aquifers and channels, groundwater, and spatial distribution of climate data. In the evapotranspiration model, the combined method of energy balance and aerodynamics is used to calculate the potential evapotranspiration or reference crop evapotranspiration. The actual evapotranspiration is obtained by multiplying the reference crop evapotranspiration by a crop coefficient and a soil coefficient if the soil moisture supply is sufficient; otherwise the actual evapotranspiration is controlled by the maximum soil water or moisture that could be evaporated. In the infiltration and recharge to groundwater model, the two-layer Green-Ampt infiltration model is employed to calculate the infiltration. The water exchanges between aquifers and channels are computed by Darcy's law, and the groundwater flow model is the numerical solution of the Boussinesq equation using the finite difference method. In the model, vegetation plays an important role in the surface flow, evapotranspiration, and infiltration simulation. For each grid cell, Manning coefficient, crop coefficient, initial soil moisture and infiltration rate are close related to the vegetation type of the grid cell.

After the input data have been processed and prepared, the model was first calibrated and validated in Ugum watershed which has both rainfall and streamflow data. And then, the calibrated model was further verified and recalibrated in the immediately adjacent 4 watersheds which also have rainfall and streamflow data. And finally, the recalibrated models were applied to a total of 12 watersheds in southern Guam including the 5 calibration watersheds to generate long term time series of streamflow (54 years or longer). The final output of long term time series of streamflow for a watershed with streamflow data is the combination of observation data collected at the USGS streamflow gage and the simulation result, while that for a watershed without streamflow data is only the simulation result.

Figure 1 below is a flowchart showing the model calibration, validation, verification, recalibration and final application for long term simulation.

Principal Findings and Significance

In this project, DEM, vegetation, soil, rainfall and streamflow data have been collected and processed, hydrologic watershed boundaries and stream networks have been delineated, and the LUOM (Luo, 2007) has been calibrated and validated in Ugum watershed and verified and recalibrated in the other 4 watersheds with both rainfall and streamflow data, which are Lasafua, Umatac, Inarajan, and Pululuc (at Tinago station), and the calibrated models were applied to a total of 12 watersheds including the 5 calibration watersheds and the other 7 adjacent watersheds. Fifty four (54) years of long term rainfall data have been composed from the observation data collected at the 9 climate stations in southern Guam, which have 15 years of or longer rainfall records. Using these long term rainfall data as input, the model generated long term time series of steamflow. The final output of the long term time series of streamflow is a combination of the observation streamflow data collected at the USGS gage if the watershed has one and the long term simulation result from the model.

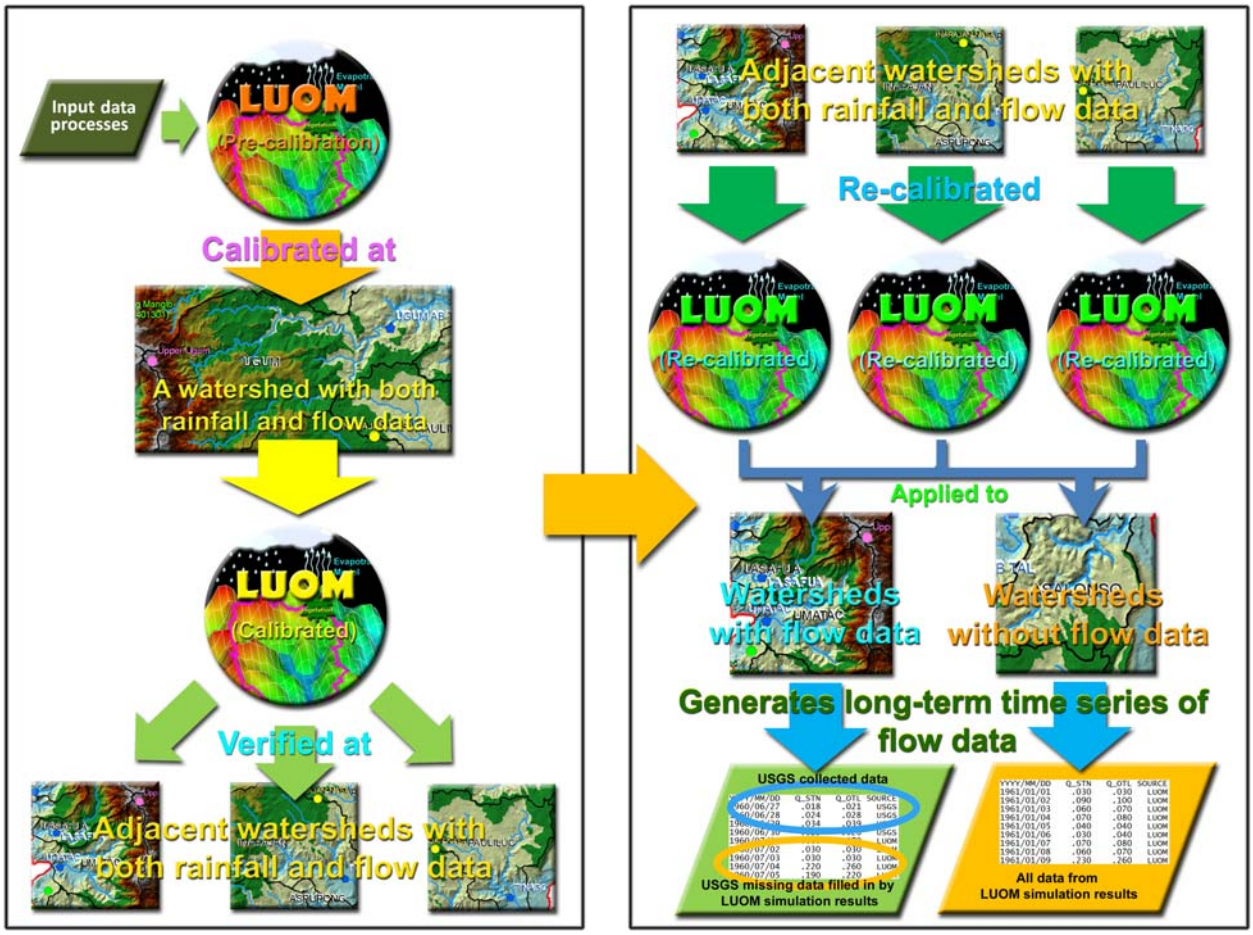

Figure 1. Flowchart of model application in southern Guam watersheds

Figure 2 shows the southern Guam watershed boundaries and stream networks (31) delineated in this project. All rain gages and flow gages available are also shown in the figure.

Ugum watershed, 19 km^2 (7.3 square mile), is located to the southwest of Talofofo Bay, and most of the watershed (97%) is covered by vegetations of ravine forest and savanna complex as named in the USGS shape file or tall vegetation and short vegetation as named in LUOM (Figures 9 and 10 in Chapter 3). The rest 3% of the watershed is barren (badland) or bare soil. The soil types mainly include Ylig clay, Akina-Atate silty clay, Akina silty clay, Togcha-Akina silty clays, Pulantat clay, Akina-Badland complex, Agfayan clay, Sasalaguan clay, rock and urban land complex (USDA et al., 1988). The elevation ranges from 3 (10 ft) to 374 meters (1227 ft). Geologically, the watershed is situated on the layer of bolanos pyroclastic member (Miocene), which comprises of breccias, conglomerates, and sandstones consisting largely of fragmented andesite. This layer is laid on the top of facpi formation (Eocene), which comprises of basal portion consisting of high-Ca boninite pillow lavas interbedded with pillow breccias, hyaloclastites, and sandstones of the same lithology.

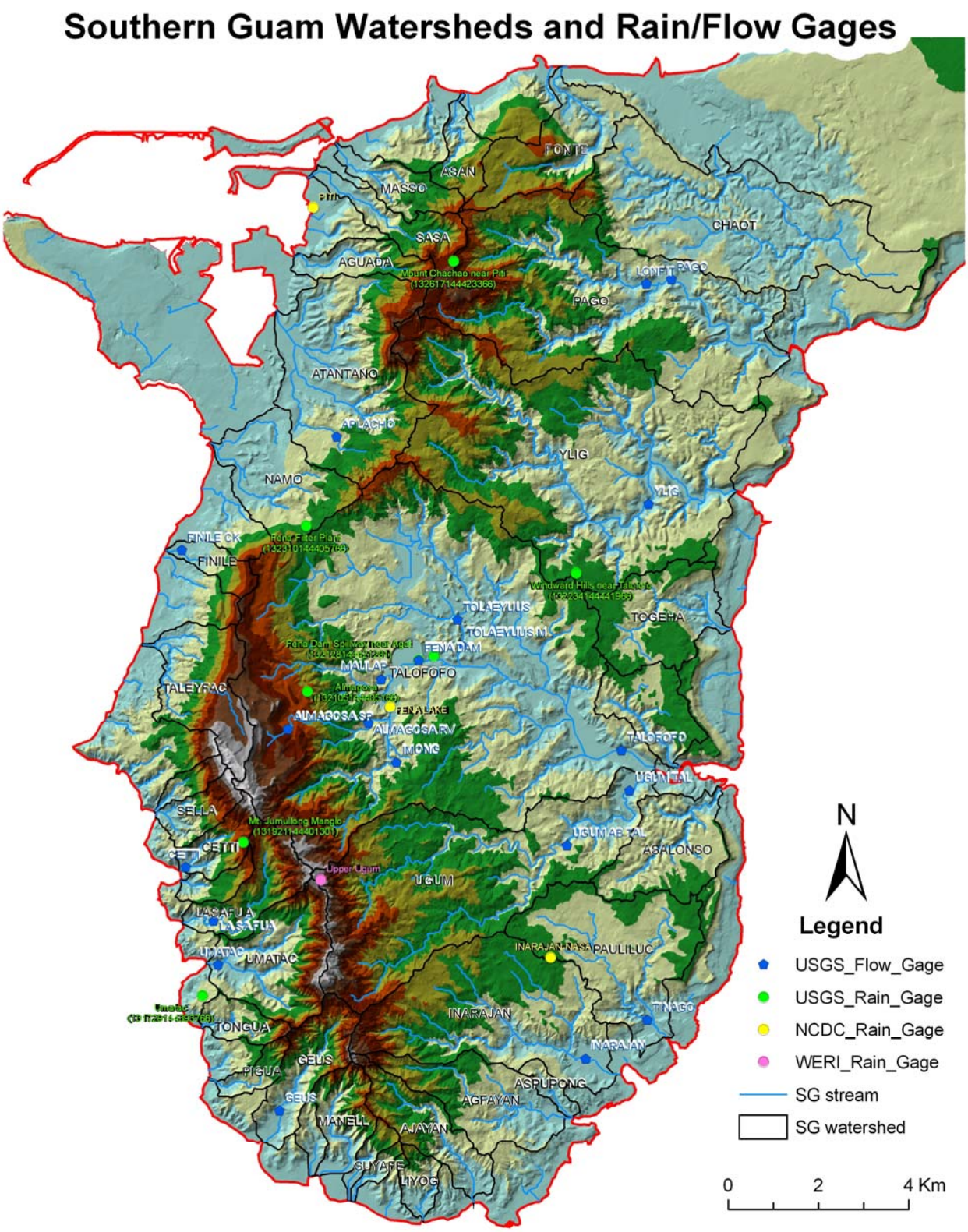

Figure 2. Southern Guam watersheds and stream networks delineated in this project
(All rain gages and flow gages available in southern Guam also shown. Background from GIS TIN data.)

Ugum watershed was selected as the first watershed for model calibration and validation because of its high availability of rainfall and streamflow data. There are a total of 7 rain gages and 2 streamflow gages located in the watershed and in its vicinity. After studying the available streamflow and rainfall data, years of 2006 and 2007 are selected for the model calibration. Consecutive rainfall data are available at WERI Upper Ugum station, USGS Umatac station, and NCDC Inarajan-NASA station. And the other two periods, 2001-2002, in which consecutive rain fall data at two USGU stations, Umatac and Mt. Jumullong Manglo, and two NCDC stations, Fena Lake and Inarajan-NASA, are available even though streamflow data in this period are not complete, and 1981-1982, in which consecutive rainfall data at NCDC station Fena Lake and Inarajan-Nasa are available, are selected for model validation. All calibration and validation are carried out at the location of station Ugum above Talofofo. Figure 3 in the next page shows the hydrographs of model calibration in 2006 (upper) and 2007 (lower).

Visually from the figure, the simulated (red) and observed (blue) hydrographs fit each other quite well overall, even though the model overestimated the first three peaks and the fifth peak a little and underestimated the forth peak a bit, and underestimated part of the recession flows in 2006, and the model overestimated the smaller peaks and underestimated the largest peak in 2007. These overestimation and underestimation are closely related to the rainfall data and thus is not systematic. Taking the second and forth peaks in 2006 as an example, one can see that the second rainfall is larger than the forth, the simulation result correctly reflects this difference in the rainfalls.

Statistically, the model efficiency coefficient (C_e), model determination coefficient (C_d) and percentage difference of volume (DV) for the two-year period of 2006 and 2007 are 0.68, 0.74 and 4.7%, respectively. The model efficiency coefficient and model determination coefficient are not very close to 1, but still good enough to demonstrate that the model behaves well. The DV shows only a very small overestimation (4.7%) of the water volume in this two-year period which is very strong evidence of the model's performance. The model's high accuracy in water volume simulation is important to water quantity related watershed management and planning.

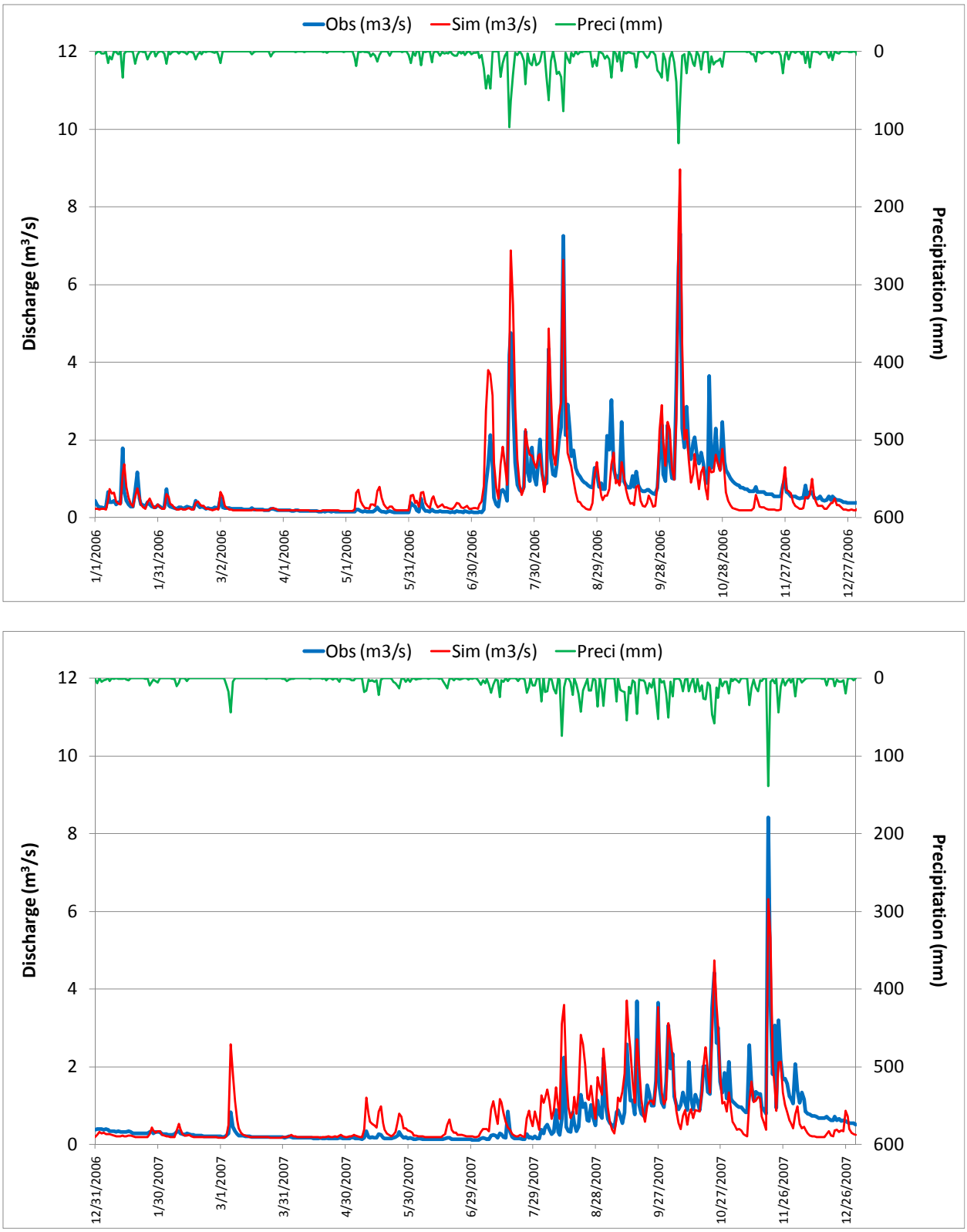

Figure 3. Comparison of hydrographs of model calibration in 2006 and 2007
(Upper-2006, lower-2007. Blue-observed flow, red-simulated flow, green-Precipitation or rainfall)

In order to expand the application of the calibrated model to other southern Guam watersheds without a streamflow gage, further verification of the model's performance in other watersheds with streamflow data is necessary. Four immediately adjacent watersheds, Pauliluc (at Tinago station), Inarajan, Umatac and Lasafua were selected for this purpose. First, the calibrated model was verified in each of these watersheds without any change in the model parameters to see how well the simulated hydrographs fit the observed ones. Then, the model was recalibrated in all these four watersheds to obtain better agreements between the simulated and observed hydrographs.

The model has been calibrated in 5 watersheds ("calibrated watersheds"), Ugum (calibrated model 1), Inarajan (calibrated model 2), Lasafua (calibrated model 3), Pauliluc (Tinago station) (calibrated model 4) and Umatac (calibrated model 5), and therefore there are a total of 5 calibrated models. These calibrated models were applied to the 12 southern Guam watersheds ("applied watersheds") to generate long term time series of streamflows. Selection of which of the 5 calibrated models that should be used was based on the criteria of geomorphologic similarity between the calibrated watershed and the applied watershed in area, elevation, aspect, slope, vegetation, soils, deposits and bedrocks. As the soils, deposits and bedrocks are pretty much the same in these watersheds, and the vegetation is a simulation factor in the model (the model has already taken the differences of vegetation into account), the criteria of similarity of area, elevation, aspect or facing, and slope play important roles in selecting the appropriate calibrated models for the applied watersheds.

As model input, long term climate data are necessary for long term simulation. Fifty four (54) years from 1955 to 2008 of long term rainfall data are composed for 9 stations. The methodology of "composition" of long term rainfall data is simply filling in the missing data or no-data using the data recorded at the most adjacent stations without any manipulation of or changes in the observation data to avoid introducing unnecessary errors of treatment to the data. If a station has no record of data in specific periods, the station is said to have "missing data." But if the station simply does not have record of data earlier than certain time (before station installation) or after certain time (after the station stops functioning), the station is said to have "no-data."

The output time series of long term streamflow for those watersheds without any streamflow data are the same as the model output, which has 54 years of data. There are 5 watersheds with no streamflow data. These watersheds are Asalonso, Agfayan (and Aspupong), Ajayan, Manell, and Sella. The output time series of long term streamflow for the other watersheds, in which there is a streamflow gage, are different from the model output. There are 7 such watersheds, which are Ugum, Pauliluc (including Tinago), Inarajan, Umatac, Lasafua, Cetti, and Geus. In the latter case, in which flow gages were installed in the watersheds, the model outputs are used to fill in the missing data and/or "no-data." This means that the observation data collected at the flow stations will be the parts of the output time series in the same periods when observation data are collected, while the model output will be the rest parts of the output time series of treamflow when observation data are not available.

Reconstructing the Ancient Rainfall-Drought History of Guam

Basic Information

Title:	Reconstructing the Ancient Rainfall-Drought History of Guam
Project Number:	2009GU154B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Drought, Geomorphological Processes
Descriptors:	West Pacific Climate Record, Speleothem, Dripwater Chemistry
Principal Investigators:	John Jenson

Publication

1. Sinclair, Daniel J., Jay L. Banner, Frederick W. Taylor, Judson Partin, John W. Jenson, John E. Mylroie, Ethan Goddard, and Terry Quinn , 2010 in review, Magnesium and Strontium Trace-Element Systematics in West Pacific Speleothems. Chemical Geology.

PROJECT SYNOPSIS REPORT

Project Title: Reconstructing the Ancient Rainfall-drought History of Guam

Problem and Research Objectives

The Guam Water Resources Advisory Council has identified as one of its research priorities "expanding and updating the rainfall database for Guam," to include long-term rainfall variability. On Guam, the long-term historical record begins only at the end of World War II. Even if the historical record were longer, however, regional climates everywhere are being shown by contemporary research to be characterized by decadal to centennial and millennial-scale oscillations, as well as apparently random shifts at any temporal scale. Determining prehistoric climate patterns thus requires using suitable proxies for historical climate conditions. In areas with limestone terrain, such as Guam, cave and cave deposits provide useful proxies for past temperature, rainfall, and sea level conditions.

This project builds on a decade of collaborative research by Dr. John Jenson of WERI and Dr. John Mylroie of Mississippi State University, in which they and their students have systematically explored and mapped the karst features and caves of the uplifted carbonate islands in the Western Pacific (Jenson et al., 2006; Keel et al., 2004a; Mylroie et al., 2001; Mylroie et al., 2006; Stafford et al., 2004a; Stafford et al., 2003; Stafford et al., 2005; Taboroši, 2000; Taboroši et al., 2005; Taboroši et al., 2004; Wexel, 2007). The current research continues this work with a classic speleological field investigation of the youngest limestone formations of Guam, which were deposited during the previous interglacial (5e) highstand and mid-Holocene highstand. In particular, caves found in these units are sources of climatic data for Guam in particular and the West Pacific region in general. Caves and cave deposits also provide unique and important clues to the history of uplift, subsidence, or eustatic relative sea-level fluctuations that emptied or flooded the cave with phreatic groundwater, as well as structural modifications, perhaps associated with seismic events, that shifted the relative positions of elements within the cave. Finally, studies of cave air and water chemistry provide important insights and constraints by which more reliable interpretation can be made from the chemical parameters and patterns revealed by laboratory analyses on cave deposits.

Methodology

The current work includes intensive and detailed field surveys to identify caves with features that may be associated with important geological or climatic events. Absolute ages calculated using the U-Th decay series (Edwards et al., 1987) established from previously collected specimens as well as new ones collected during the ongoing study, will be incorporated into laboratory analyses from previous related projects (Sinclair et al., 2008). Cave survey work began in May 2009 and continues to the present. The basic products include detailed maps, with accompanying chronologies and descriptions of the inferred history of the caves as represented from the maps.

Principal Findings and Significance

This project is helping to discern the sequence of events and conditions, including not only their relative timing but perhaps some absolute ages as well, that produced the youngest limestone formations on Guam. The current work focuses on the interglacial Terague Limestone. Field and laboratory work is focused on the original environment and characteristics of the wall rock in which the caves formed and the onset of dissolution that initiated the development of the caves. In particular, we are attempting to discern the history of uplift, subsidence, or eustatic relative sea-level fluctuations that emptied or flooded the cave with phreatic groundwater, as well as structural modifications, perhaps associated with seismic events, that shifted the relative positions of elements within the cave. This, in turn, will provide a means by which to locate and better interpret promising specimens of cave deposits from which to reconstruct the prehistoric climate record of Guam and the surrounding region.

Impacts of Land Cover Change on Groundwater Quality in Guam

Basic Information

Title:	Impacts of Land Cover Change on Groundwater Quality in Guam
Project Number:	2009GU156B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Groundwater, Methods, Methods
Descriptors:	Land Cover Change, Impacts, Groundwater Quality
Principal Investigators:	Yuming Wen

Publications

1. Wen, Yuming, 2009, Change Detection of Land Cover in Northern Guam, Proceedings of the 6th International Symposium on Digital Earth: Digital Earth in Action, September 9 – 12, 2009, Beijing, China, p45
2. Wen, Yuming and Maria Kottermair, 2009, Water Quality Data Preparation for GIS Analysis, 30th Annual College of Liberal Arts and Social Sciences (CLASS) Research Conference, University of Guam, March 10, 2009, Abstract p7

PROJECT SYNOPSIS REPORT

Project Title: Impacts of Land Cover Change on Groundwater Quality in Guam

Problem and Research Objectives

Guam, an unincorporated U.S. territory in the western Pacific, is the largest (about 541.3 km^2) and southernmost island in the Mariana Islands. Ground water supplies about 80% of the drinking water for the island's about 180,000 residents and over one million visitors annually. In northern Guam, water is pumped from over 100 wells, most of which are located in the northern Guam. Because of run-off and human activities, and unreliable drinking water delivery systems and management, the potential for contamination is high.

At its 12 September 2008 meeting, the WERI Research Advisory Council for Guam identified *impact of past use of banned pesticides and organic substances on surface and groundwater*, and *identification and mapping of the sources, locations, movement, and fate of petroleum and other groundwater contaminants under northern Guam* as some of the highest priority research needs for Guam. Based on the above statement, groundwater quality is a main concern in Guam. This project aims to address the above mentioned issue. The water quality data from drinking wells in Guam from 1996 to 2009 are available. Landsat Satellite images of 1973 and 2001, and the 2006 QuickBird image are available. The project incorporates all the data collections from Guam Waterworks Authority (GWA) into GIS data formats for each contaminant that has so far been detected. The relationships between land cover change and some commonly occurring contaminants, e.g. fecal coliforms, chlordane, tetrachloroethylene (PCE) and trichloroethylene (TCE) are evaluated.

The main objectives of this project are listed as follows:

1. Preprocessing of Landsat images for derivation of land cover information;
2. Classification of land cover information from available Landsat and QuickBird images;
3. Evaluation of the relationship between land cover change, particularly human-induced activities and groundwater quality;
4. Temporal and spatial changes in the distribution and abundance of frequently occurring chemical and biological contaminants

Methodology

GIS, remote sensing, spatial analysis and geospatial statistics are used to complete the project. GWA provides 1996-2009 water quality data for all drinking water production wells in service between 1996 and 2009. Well locations, and sub-basin information are also available from this agency. Landsat image of 1973 and QuickBird image of 2006 are used. The GIS Lab at the Water and Environmental Research Institute (WERI) is equipped with the state of the art computers, ERDAS IMAGINE and ArcGIS software with extensions such as Spatial Analyst and Geostatistical Analyst. ERDAS Imagine is used to conduct land cover classification. ArcGIS is applied to link GWA water quality

data to well locations, and is utilized to evaluate the relationship between human-induced activities and groundwater quality.

Principal Findings and Significance

Erdas Imagine software is applied to derive the above mentioned land cover from satellite imagery, and change detection of land cover can be determined by temporal land cover information.

Based on the analysis of land cover information derived from Landsat MSS image of 1973 and QuickBird Image of 2006, most of the northern Guam was covered by vegetation, i.e., forest and grass in 1973 and 2006. The total area of forest increased by 14.4% from 1973 to 2006, while the total area of grassland decreased dramatically by 72.4% from 1973 to 2006. However, the total area of vegetation including forest and grass decreased by about 12.1% from 1973 to 2006, which could be accounted for by human-induced activities, particularly urban development in the past few decades in Guam. The urban area increased from about 22% to 30.3% between 1973 and 2006, and the trend will continue in the coming years because of extensive military buildup activities caused by the relocation of about 8600 marines from Okinawa to Guam up to 2014. The following table presents more details about land cover change from 1973 to 2006 in the northern Guam.

Land Cover Change Detection in Northern Guam from 1973 to 2006

1973 \ 2006	Forest	Grass	Bareland	Urban	Water	Total
Forest	144808	9889	1289	19912	204	176102
Grass	36116	10327	1575	29286	312	77616
Bareland	163	35	13	72	0	283
Urban	20446	1169	677	49455	124	71871
Total	201533	21420	3554	98725	640	325872

1973 \ 2006	Forest	Grass	Bareland	Urban	Water	Total
Forest	82.23%	5.62%	0.73%	11.31%	0.12%	54.04%
Grass	46.53%	13.31%	2.03%	37.73%	0.40%	23.82%
Bareland	57.60%	12.37%	4.59%	25.44%	0.00%	0.09%
Urban	28.45%	1.63%	0.94%	68.81%	0.17%	22.05%
Total	61.84%	6.57%	1.09%	30.30%	0.20%	100.00%

Since the groundwater quality data provided by GWA is stored in Microsoft Excel spreadsheet format, it needs to be geocoded for further analysis in GIS. The geocoding process links the Excel spreadsheet data to well locations, therefore groundwater quality data can be saved in GIS formats, i.e., shapfiles for this research so that GIS can be

utilized to process and analyze the groundwater quality data to locate problematic wells. This project mainly focuses on commonly occurring contaminants such as fecal coliform, chlordane, PCE and TCE, locating problematic wells, and evaluating relationships between such contaminants and land cover change, particularly human-induced activities such as urban development. GIS-based analysis of the fecal coliform data from 1998 to 2009 indicates that the wells of A-23, A-25, A-30, A-31, EX-5A, F-4, F-11, F-17, Y-3, Y-9, Y-14 and Y-23 have problems with occurrences of fecal coliform (Figure 1). The wells of A-13, A-18, AG-1, D-7, D-19, D-20, D-22, F-19, M-9, Y-1 and Y-2 have potential risks in occurrences of fecal coliform (Figure 2).

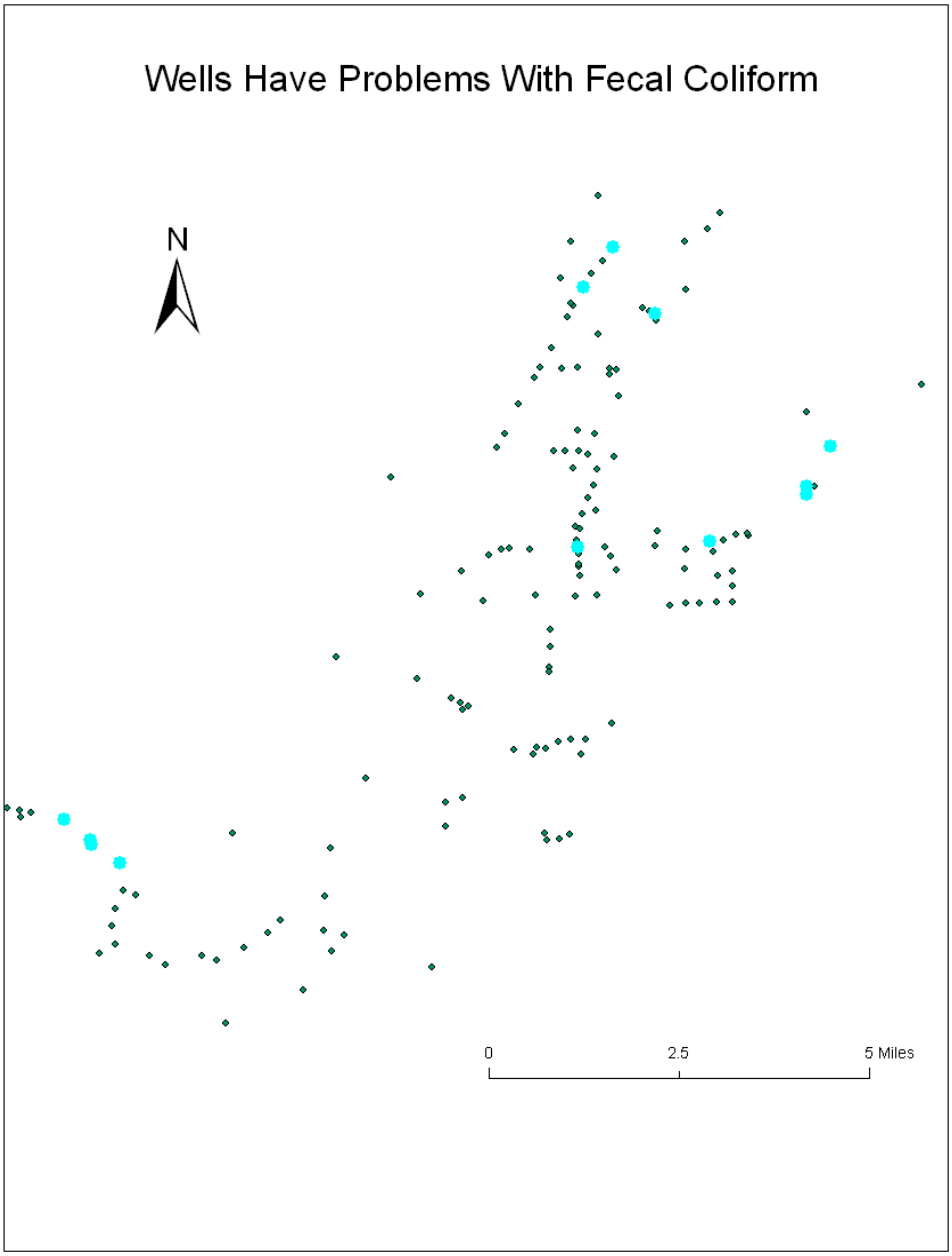

Figure 1. Wells with high frequency of occurrences of fecal coliform (Green dots)

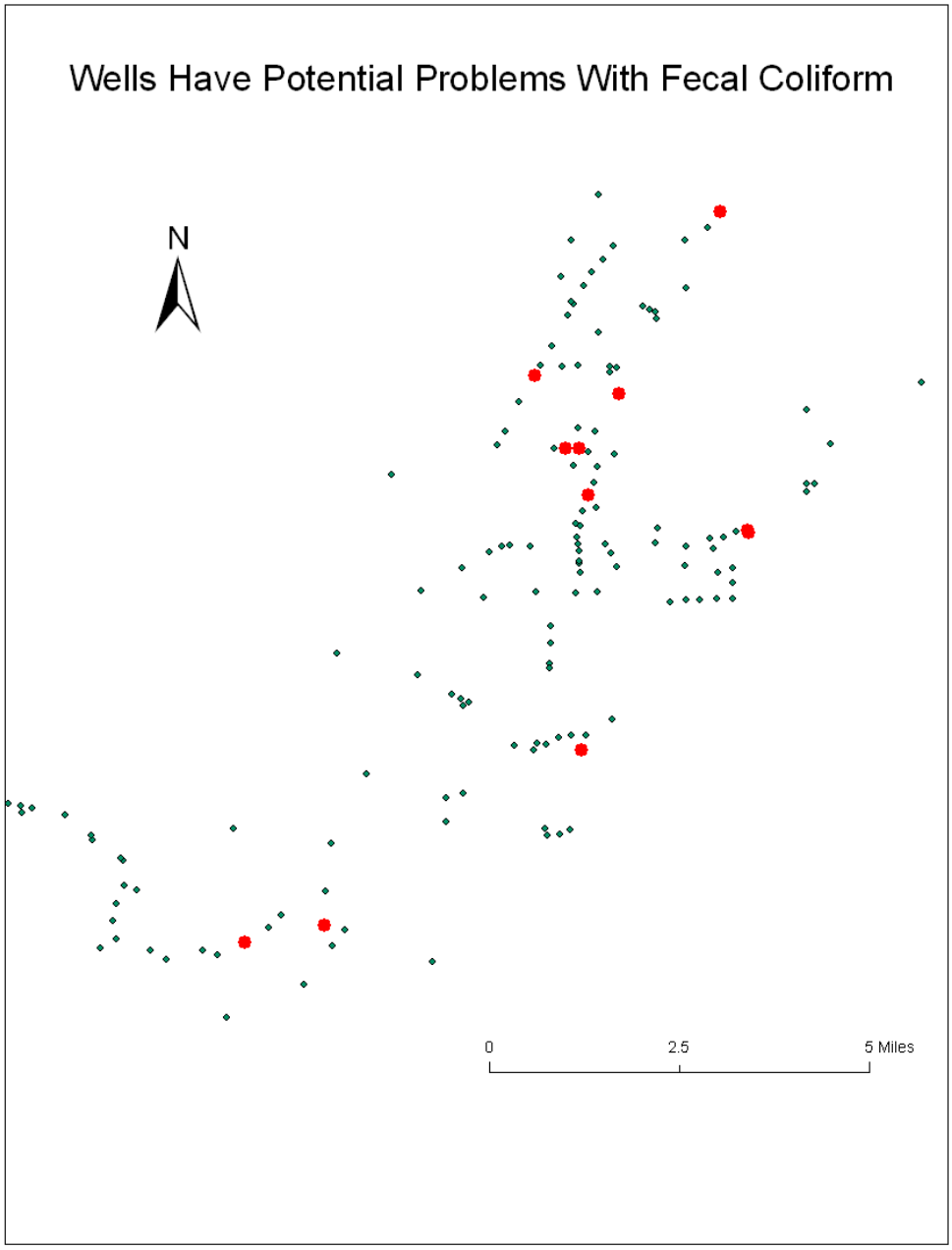

Figure 2. Wells with potential risk of occurrences of fecal coliform (Red dots)

When ArcGIS software is used to analyze the TCE data, no wells have problems with TCE. However, three wells, i.e., A-17, D-5 and NAS-1 have potential risk in high level of TCE (Figure 3).

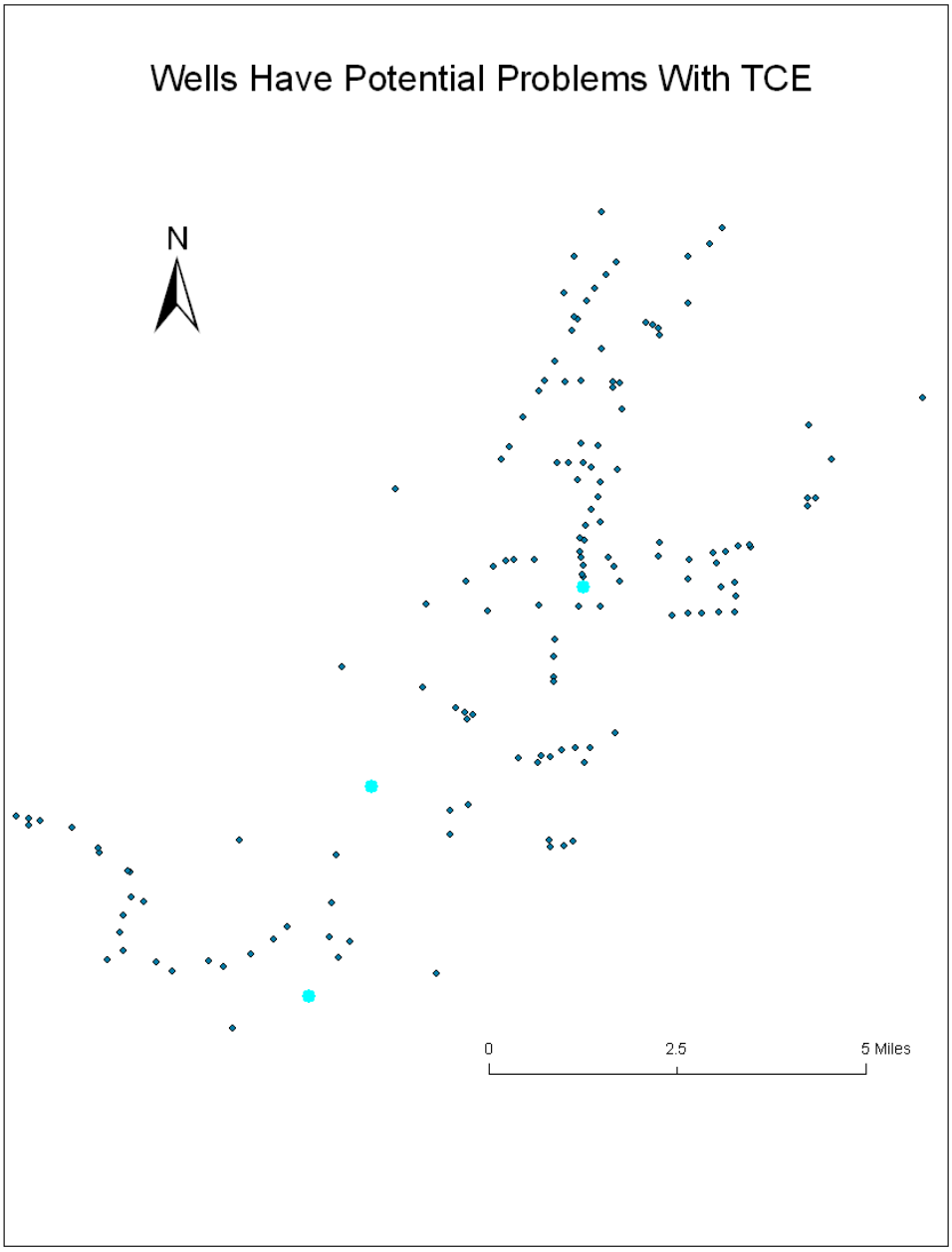

Figure 3. Wells with potential risk in high level of TCE (Green dots)

Query of the PCE data indicates that no wells have problems with PCE. Only two wells, i.e., A-5 and A-30 were detected low level of PCE in most of detection periods (Figure 4).

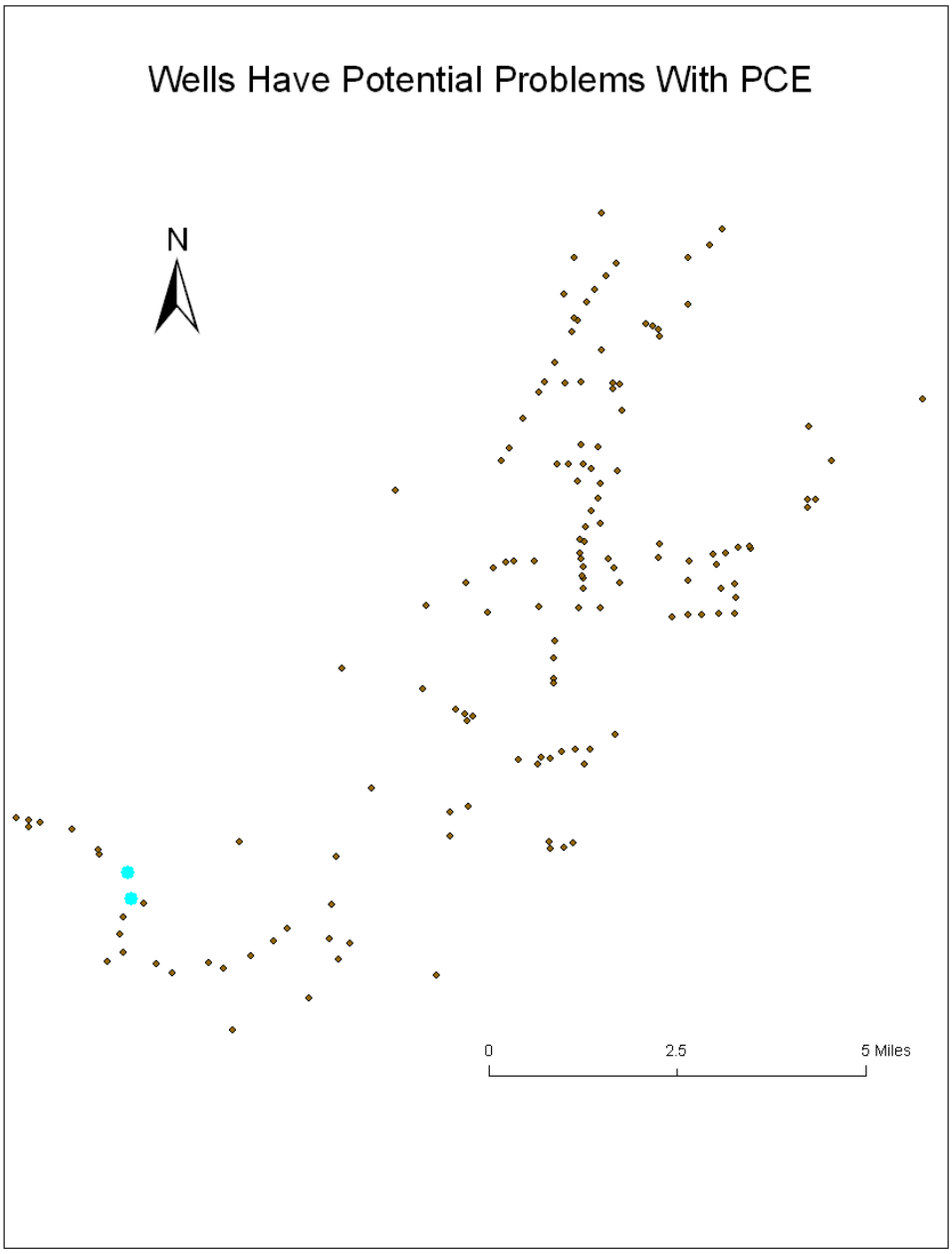

Figure 4. Wells with potential risk in high level of PCE (Green dots)

There are five wells with potential problems with chlordane contamination, though the chlordane contaminant levels for all of the wells did not exceed the maximum contaminant level (MCL). These wells are A-25, D-15, GH-501, M-14 and M-18, especially the well M-14 (Figure 5).

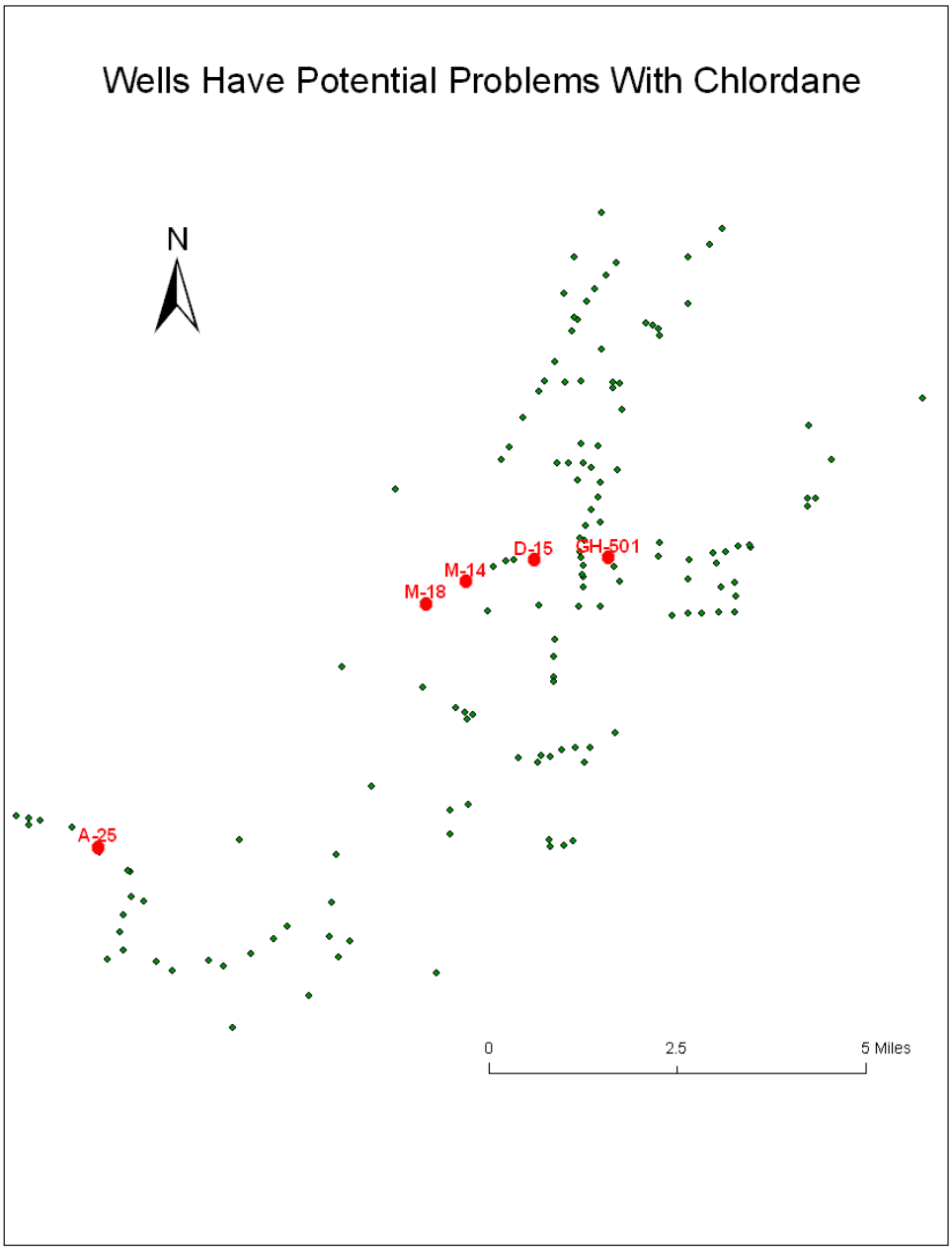

Figure 5. Wells with potential risk for chlordane contamination (Red dots)

Wells with potential PCE problems are located in urban areas. Wells with potential chlordane risk are located in grassland. Wells with fecal coliform problems are usually located in urban areas or close to urban areas. Wells with potential TCE contamination are also located in or close to urbanized areas. The change detection of land cover from 1973 to 2006 indicates that human activities, particularly urban development caused loss

of vegetation in the northern Guam. More impervious surfaces will be created with the upcoming military buildup activities in Guam.

The findings and methods used in this project are of interest to some agencies. The Government of Guam, and particularly GWA and Guam Environmental Protection Agency (GEPA) is interested in groundwater quality, land cover information, and land cover change. Groundwater quality data, and land cover information in different dates may help researchers, water resource engineers, land managers, local, state or federal government agencies, particularly GWA, GEPA and US EPA provide better groundwater management, and better understand how groundwater quality was affected by human-induced activities such land cover change. Such data or analytical results are also important to aquifer protection and environmental monitoring and analysis.

Sustainable Well Yield Determinations Using Conductivity Probes on Active Wells

Basic Information

Title:	Sustainable Well Yield Determinations Using Conductivity Probes on Active Wells
Project Number:	2009GU159B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Water Quality, Groundwater, None
Descriptors:	Groundwater, Salinity, Saipan
Principal Investigators:	Derek Chambers

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Sustainable Well Yield Determinations Using Conductivity Probes on Active wells

Problem and Research Objectives

The major source of drinking water for the island of Saipan is groundwater pumped from the karst (fractured limestone) aquifers by the local water utility, the Commonwealth Utilities Corporation (CUC). The most productive (most heavily pumped) well fields on Saipan are located over the basal lens aquifers, where the fresh water lens floats on salt water. Poor well construction (penetration through the fresh water lens), poor pump placement (too far below dynamic water levels), and over pumping have resulted in salt water intrusion at individual wells and well fields. The volume-weighted chloride ion concentration from the total amount of water pumped from wells on Saipan is about 1,100 mg/l, well above the USEPA recommended limit of 250 mg/l. In fact, the chloride ion concentration at individual wells can on occasions exceed 3,000 mg/l.

In order to improve the quality of the water pumped from the basal lens aquifers on Saipan, a reliable method needs to be developed to determine the sustainable yield for individual wells, while minimizing the chloride ion concentration. This project proposes to use conductivity probes in active production wells to measure electrical conductance (EC) of groundwater in three wells, to determine the highest sustainable yield while trying to keep the chloride ion concentration below 250 mg/l. The probes will also be used to determine the drawdown at each well, so that the pump intake can be placed at the highest possible elevation. This project also addresses the critical State water quality issue regarding a baseline for season and usage related changes in salinity in drinking water production wells.

The ultimate goals of the study are to develop a method to optimize the pump rate and pump depth setting for individual wells to minimize chloride ion concentration in the groundwater delivered to customers on Saipan.

Methodology

Three active production wells in one well field will be studied simultaneously in the following manner: A 1-1/4 inch diameter sounding tube will be installed such that it penetrates the well cap and extends to 5 feet above the bottom of the hole. The sounding tube will be screened from 5 feet above the static water level to the bottom end of the sounding tube. A conductivity, temperature, depth (CTD) probe will be lowered into the sounding tube to measure and record the conductivity profile of the well during static conditions and compared with the profile measured later during pumping conditions. Recording conductivity values in two adjacent wells will help determine how pumping rates in one well affects nearby production wells.

Principal Findings and Significance

Progress during this reporting period, March 1, 2009 – February 28, 2010:

1-1/4 inch diameter PVC well casing and well screen are to be used as sounding tubes for the conductivity probes that will be installed in three wells. Quotes for the well screen and casing were solicited from three vendors. The well screen and casing were purchased from a vendor in Oregon. The well screen and casing have been shipped to Saipan and are now available for installation in the selected wells.

Quotes for conductivity, temperature, and depth (CTD) probes were solicited from three vendors. The probes were purchased from a vendor in Ontario, Canada. The probes have been shipped to Saipan and are now available for installation in the selected wells.

This project was granted a no-cost extension until February 28, 2011.

Development of Optimal Operation of Saipan's Water Distribution System Using a Newly Developed Hydraulic Model

Basic Information

Title:	Development of Optimal Operation of Saipan's Water Distribution System Using a Newly Developed Hydraulic Model
Project Number:	2009GU160B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Distribution Systems, Model Studies, Water System Operation, Water Production, Water Demand
Principal Investigators:	Shahram Khosrowpanah, Mariano Iglecias

Publication

1. Khosrowpanah, Shahram, 2009, Development of Junction Water Demands for the Saipan Water Dist. System numerical Model, Proceeding of the 2009 American Water Works Association AWWA DDS Conference, Reno, Nevada, August 30, 2009.

PROJECT SYNOPSIS REPORT

Project Title: Development of Optimal Operation of the Saipan's Water Distribution System using New Developed Hydraulic Model

Problem and Research Objectives

Water hours and low delivery pressure have long been a part of the daily lives of the people in the islands of the Western Pacific. In Saipan, Commonwealth of the Northern Mariana Islands (CNMI), large investments have been made in system improvements, but delivery problems still exist. A stated goal of the CNMI government is to provide 24-hour water to all residents served by the Commonwealth Utilities Corporation (CUC) water system. This goal will be unattainable until the CUC has complete knowledge of their water delivery capabilities and system operation.

Over the years the CUC water distribution system has grown and new wells have been added to the system. This physical expansion has been well documented, but improvements in the hydraulic characteristics and delivery capabilities of the entire system have never been fully examined.

Recently, Stipulated Orders have been filed in the US District Court for the Northern Mariana Islands to compel the utility company to adhere to federal regulations governing water, sewer, and power (Eaton, 2008). As part of this act, CUC should develop a hydraulic model of the water distribution system that will be used for system improvement, system operation, and future system expansion.

Researchers at university of Guam Water and Environmental Research Institute of the Western Pacific (WERI) developed computerized models of each of the fifteen sub-regions of the CUC water system using the Haestad WaterCAD water system modeling program. Later on, they developed a source, transmission and storage model of the Saipan water system. This includes a skeleton of the existing 15-region water system models that are joined together at the boundary points as shown in Figure 1. Using Geographic Information System (GIS) capability and Saipan's 2003 census data the WERI researchers determined the number of users at each system junction node for residential and commercial customers (Heitz, Khosrowpanah 2008). During the past several months WERI researchers collected the flow production from the renovated wells during dry and wet seasons. To comply with the stipulated order there is a need to update the hydraulic model and input the inflow/outflow to the system and determine the optimum system operation.

The overall goal of this project was to update the Saipan water distribution model and to explore the most effective means of transferring the water sources between the regions. The specific objectives of this project were to:

1. Update the skeleton model of the CUC water distribution that reflects all the new subdivisions that have been added to the whole system.
2. Determine the amount of water production in each sub-region.
3. Using Geographical Information System (GIS) techniques, locate all production sites.

4. Explore various operational scenarios for effectively transferring water throughout the regions.

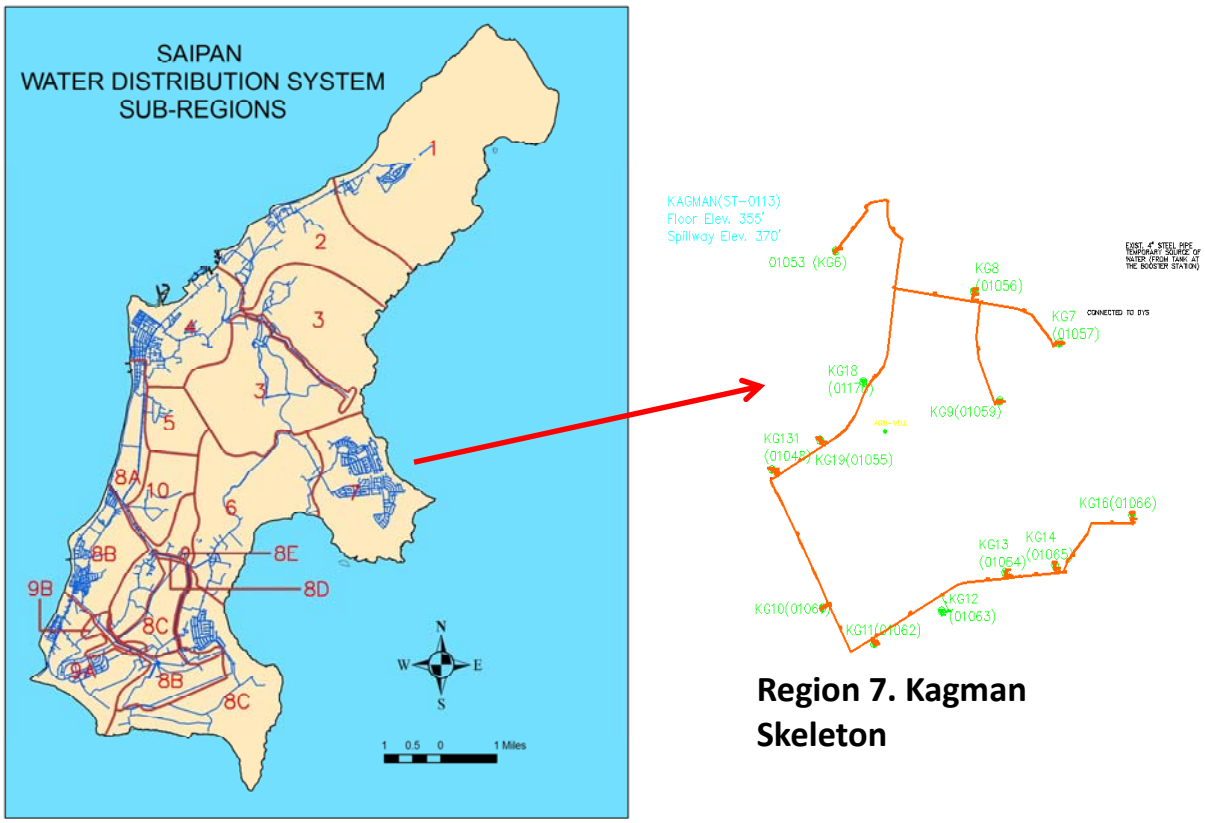

Figure 1. Saipan's Water Distribution System.

Methodology

The steps that were taken to complete the goals of this project were to: update the Saipan water distribution model by adding the new development that has been constructed since water distribution model was put together by WERI researchers, entering the amount of water that each production well produces to the model, and running the model with various operational scenarios. We also overlaid the water distribution model in Saipan's map using GIS technique for identifying the coordinate of all production wells in the system.

The first step of this project was to update the model. The water distribution model of Saipan was completed in 2006. As shown in Figure 1 (region 7 as an example) it includes the transmission lines, valves, pumps, and storage tank. Two major developments have been competed by CUC which are shown in Figure 2, and 3. Using

Heastad Water Distribution Model, the physical components of the water distribution system for the new developments were input to the skeleton of the water distribution for regions 3 and 6. The model updating should be continued for any new water development in the future.

The next step was inputting the inflow information from production wells into the system. Table 1 shows the amount of water that each production well produces. This information was inputted as a fix inflow to the system. Although considering that each production well produces a fix amount of water is not a good practice, because during the day when demands changes, the pumping rate should change according to each pump curve at the wells. However, when there is not information on the pattern of water use the model will generate data on the amount of water that each region produces. Then the operators will know where they can transfer water to regions that are in water shortage.

We explored various operational scenarios to improve the import and export of water between sub-regions whose production exceeds their use to those whose production is less than their required customer demands. This task will be continued by CUC when the Heastad model will be loaded into their computer system. We are in process of purchasing a new XP-Computer for CUC to enable them to run the model with various management practices for providing 24-hours service to all of their customers.

The last task was inputting each region of the CUC skeleton model into a Geographic Information System (GIS) map of Saipan as shown in Figure 4. This will identify coordinate of each water system component and also will be used in the future for creating a data base of the water system.

Figure 2. New development, San Vicente, Saipan.

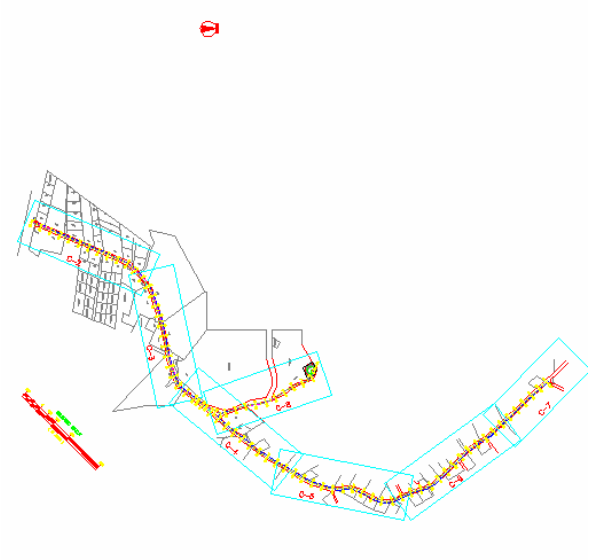

Figure 3. New development, Kannat Tabla, Saipan.

Table 1. Well data for Saipan Water Distribution System

GPS way#	Time	Well #	Sub-Region	Well reading June (gpm)	Well reading Aug (gpm)	Pressure at well June (PSI)	Pressure at well Aug (PSI)
70	1.45	IF-206	8A	50		18	
71	2.15	IF-203		40		20	
72	2.30	IF-202		44		15	
73		IF-201		44		12	
74		IF-21		45	Down	18	
75		IF-20		37	40	20	19
76	2.52	IF-19		34	32	17	20
77	3	IF-22		30	30	2	8
78	3.05	IF-108		50	50	2	0
79		IF-102		46	48	1	5
80		IF-11		DW	54		8
81	3.15	IF-106		48	50	0	0
82	3.31	IF-16					
83	9:40	OB-5	8B	32		15	
84		OB-6		43		21	
85	9:50	OB-7		43		18	
85	OUT	OB-8					
86		OB09		43	45	19	16
87		OB-10					
88	10:00	OB-11		45		18	
89	10:10	OB-12		50		2	
90	10:12	OB-13		45		14	
91	10:20	OB-24		53		21	
92	10:35	OB-23		51		20	
93	10:40	OB-22		53		22	
94	10:42	OB-19		52		21	
95	10:53	OB-21	8B	50		16	
99	10:58	OB-20	8B	47	48	10	5
100	10:58		8B				
101	11:05	OB-16	8B	55		11	
102		OB-17		41		34	
103		OB-18	8B	55		30	
104		IF-23		48	50	N/W	0
105	11:20	IF-24	8B	36	38	10	10
106	11:32	IF-208		50	48	N/W	0
107	11:40	IF-28	8B	55		N/W	
108		CL-2	REG. 4	140		10	
109	2:11	PR-164		48		10	

110	2:13	PR-162		20		60	
111		SQ-13		50	34	8	0
112		SQ-11		26	30	N/W	N/W
113		SQ-10		48	32	0	0
114		SQ-5		35	OFF		
115		SQ-9		31	Off	68	
116		SQ-7	REG 4	56	OFF	22	
117		SQ-150					
118	3:03	MAUI-IV SHAFT	151248.6 145.4428.8	350	350		6
119		SQ-148	REG.2	75	78	60	55
120		SQ-4		66	65	60	64
121		CH-3	REG.3	45		30	
122		CH-1		56			
123		DONNIE SPRING					
124	9:35	DD-8	8C	75		50	
125	9:51	OB-2	8C	25		15	
126	10:00	OB-14	8C	40		20	
127	10:00	OB-15	8C	26		15	
128	10:00	OB-1	8C	N/W		30	
129	10:09	IF-18		35	34	10	10
130	10:09	IF-105		78		N/W	
131	10:09	IF-4		36		25	
132	10:09	IF-3		51		25	
133	10:09	IF-1	8C	52		18	
134	10:09	IF-211	8C	40		5	
135	10:44	IF-220		52		0	
136	10:44	IF-5		60		0	
137	10:52	IF-7		51	50	18	19
138	10:56	IF-8		42	42	18	19
139	11:03	MAUII SHAFT I	REG 9A	450			
140	11:03	AS-1	8C	66	66	20	26
141	11:03	AS-2	8C	50	46	40	49
142	11:39	AS-5	8C	42	41	45	55
143	9:53	MQ-10	REG 1	N/W		79	
144	10:00	MQ-3	REG 1	N/W		8	
145	10:00	MQ-1	REG 1	90		11	
146	10:12	MQ-8	REG 1	35		8	
147	10:41	AGAG-45	REG 3	N/W			
148	10.41	AGAG-	REG 3	120	105	20	22

		50					
149	10:41	AGAG-70		110	110	11	11
150	10:41	AGAG-73		110	2125	130	62
151	10:41	AGAG-121		110	114	10	10
152	11:15	KG-2	REG-6	43	40	60	60
153	11:15	KG-3	REG 6	48		62	
154	11:15	KG-4		55		60	
155	11:15	KG-131		220			
156	11:35	KG-19	REG 7	32		10	
157	11:45	KG-6	REG 7	62	65	60	60
158	11:45	KG-9	REG 7	35		40	
159	11:55	KG-15	REG 7	36		52	
160	11:55	KG-7		N/W		10	
161	11:55	KG-10	REG 7	30		10	
162	12:08	KG-11	REG 7	33		8	
163	12:08	KG-12		40		12	
164	12:08	KG-13		40		N/W	
165	12:08	KG-14		43	165		
166	11:15	SV-7		55		10	
167	12:35	SV-1		25			
168	1.45	KV-17	9A		75		20
169		KV-116	9B		60		60
170	11	KV-12			56		8
171	11.06	KV-13			66		50
172	11.12	KV-21			66		5
173	11.15	KV-22			65		10
174	11.18	KV-24			66		12
175		KV-25			66		30
176		KV-20			60		75
181	2.40	GR-151	5		75		20
182	3	GR-5			42		5
191	9.48	IF-101			55		32

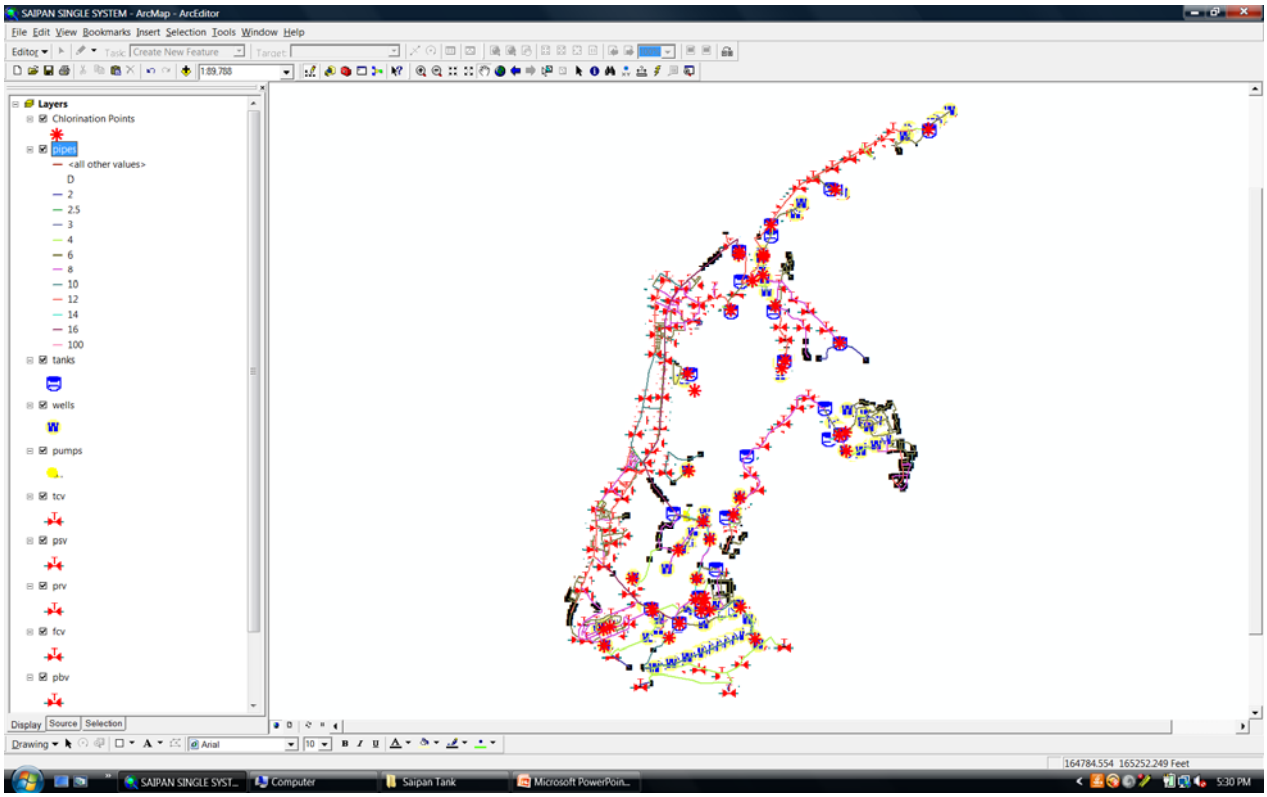

Figure 4. GIS view of the entire CUC's water distribution system.

Principal Findings and Significance

The skeleton of the Saipan water distribution system has been updated. It reflects all new development that has been in place since 2006 when the model was developed. The water production from wells that has been renovated since 2009 has been inputted into the model. This will help CUC to transfer water among the regions that are in water shortage. As the results, presently 60 percent of the customers are on 24-hours water. Currently CUC is in process of installing new smart meters throughout the system. This will help the researchers to develop water use patterns for various customers such as households, hotels, schools, laundries, and water bottling companies. This information will help to calibrate the system and then CUC can explore various scenarios of system operation. This will help the CNMI government reach its goal of providing 24-hour water to all residents served by the Commonwealth Utilities Corporation (CUC) water system. We are in process of developing a GIS data base for CUC water distribution system. The data base will include the description of each component of the CUC water system and system inventory. This will help streamline the operation of the CUC water distribution system.

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Heitz L. F., S. Khosrowpanah, 2008, “Development of Junction Demands for the Saipan Water System Numerical Model”, Water and Environmental Resources Research Institute (WERI), University of Guam, Technical Report No. 122, 37pp.

Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon

Basic Information

Title:	Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon
Project Number:	2009GU162B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Sediments, Non Point Pollution, Toxic Substances
Descriptors:	Sediments, Heavy Metals, Storm Water Runoff, Wastewater Discharges, Saipan Lagoon
Principal Investigators:	John Starmer, Gary Denton

Publication

1. Denton, Gary R.W. and John A. Starmer, 2009, What's in Your Storm Drain? Asia Pacific Academy of Science and Environmental Management Research Conference, American Memorial Park Auditorium, Saipan, November 24-25, 2009, Abstracts, p. 10.

PROJECT SYNOPSIS REPORT

Project Title: Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon

Problem and Research Objectives

Saipan is the second most densely populated island in Micronesia and experiences many of the environmental pollution problems seen in the larger industrialized nations of the world. Solid and hazardous waste disposal, illegal dumping, urban runoff, unregulated waste discharges from various commercial premises, and the disposal of primary treated sewage effluent directly into the ocean, rank among the most critical environmental problems seen on the island today. A large lagoon that borders the western side of the island serves as a sink for many of the more recalcitrant pollutants mobilized into the ocean from land-based sources during major storm events. Locally referred to as Saipan Lagoon, this body of water is geographically divided into three separate lagoonal entities all of which are impacted to some degree by the activities of man. The largest and most northerly of these is Tanapag Lagoon, which extends along some of the most industrialized coastline on island. Centrally located is Garapan Lagoon, a relatively long narrow stretch of water that borders both residential and commercial premises between the villages of Susupe in the south and Garapan in the north, and receives stormwater from numerous storm drains along its entire length. Chalan Kanoa Lagoon is the smallest and most southerly member of the trio and borders mostly rural and residential areas. It receives relatively little in the way of stormwater runoff although it was used as a solid waste disposal site for many years and has a primary sewage treatment plant located at its southern end.

A pollution monitoring and assessment program for the northern half of Saipan Lagoon (Tanapag Lagoon) was initiated by WERI in 1997. The study identified heavy metals as the contaminants of primary concern within this region (Denton *et al.* 2009, 2008, 2006, 2001). The distribution and abundance of these pollutants in the two lagoonal entities further south is currently under investigation and is seen as a logical extension of the work already completed. The study reported here focuses on heavy metals in surface sediments within this area. Complementary investigations are also underway to determine contaminant levels in fisheries resources and other dominant ecological representatives from these waters. The primary objectives of the overall program are to: a) establish a reliable contaminant database for Saipan Lagoon with which future findings can be compared and evaluated, 2) identify possible 'hotspots' and delineate areas of contaminant enrichment, and 3) assess the degree of contamination and possible impact on human health by reference to levels reported in biotic and abiotic components from clean and polluted environments elsewhere.

Methodology

Surface sediments were collected at discharge points of 16 storm drains within the study area and at offshore sites located 10-m, 25-m, 50-m, 100m and 250-m intervals seaward along transect lines running perpendicular them (Figure 1). Where possible, samples were also collected at 500-m and 1000-m offshore. The precise location of each offshore sampling site was determined by GPS and reached by small motorized boat. Samples (~100 g) were gently scooped up in hand-held, acid washed plastic containers so as not to disturb surface layers. Three separate samples were taken within an approximate 3-m diameter circle at each site. In the laboratory, all

samples were dried at ~30 °C and sieved through a 1-mm plastic screen in preparation for analysis. All samples were largely composed of fine carbonate sands with variable amounts of organic matter, silt, clay and terrigenous material.

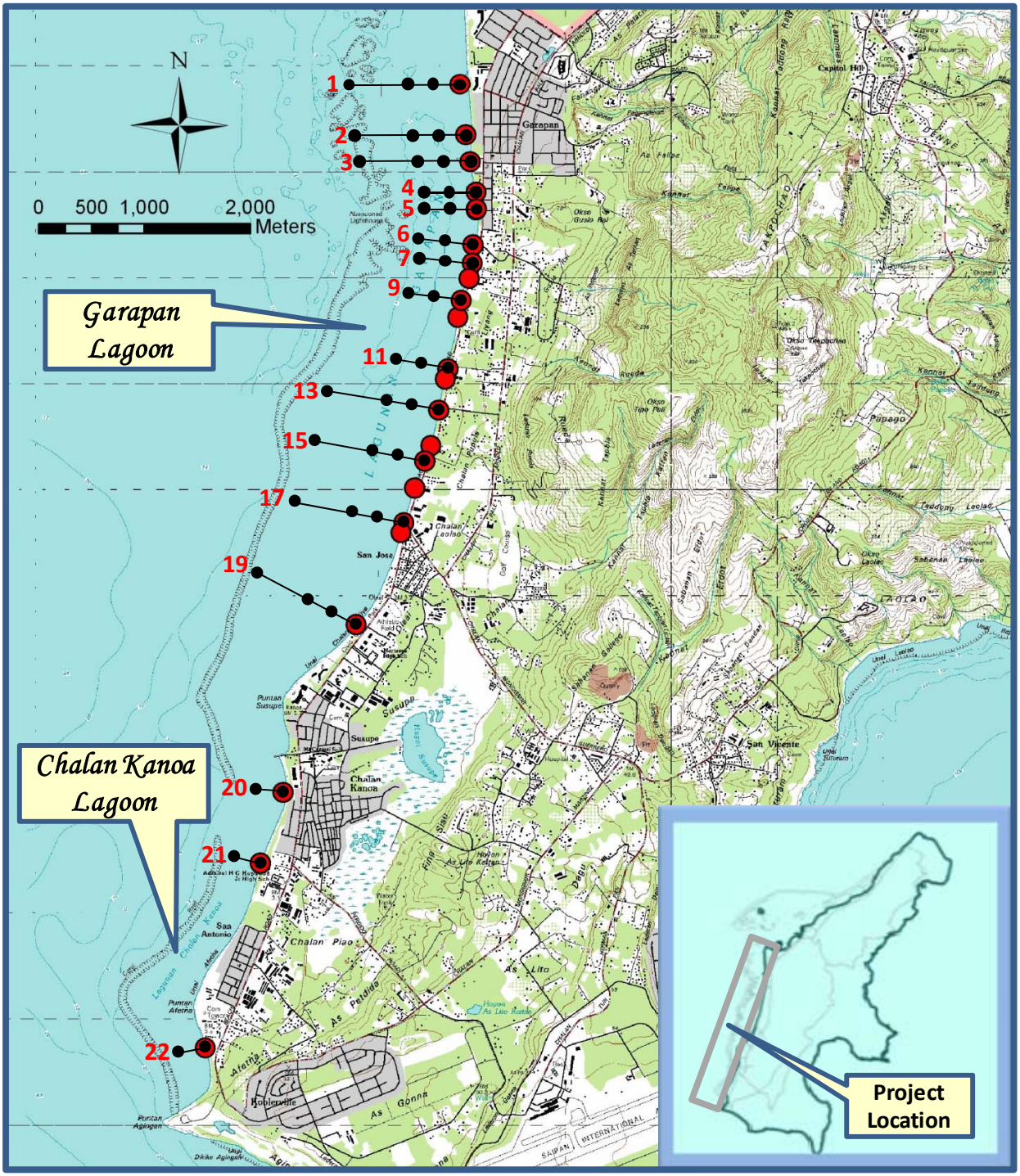

Figure 1: Map of Saipan (15°12'N, 145°43'E) showing project location (inset), and transect lines extending seaward from 16 of 22 coastal stormwater discharge points that currently exist along the southern half of Saipan Lagoon. Closed black circles represent 0-m, 250-m 500-m and 1000-m sampling sites only. Intermediate sampling sites at 10-m, 25-m, 50-m and 100-m not shown here.

All sediment samples were analyzed for heavy metals (Ag, Cd, Cu, Cr, Fe, Hg, Mn, Ni, Pb and Zn) by atomic absorption spectroscopy (AAS) following conventional wet oxidation in hot nitric acid. This digestion procedure is essentially similar to EPA method 3050A, SW-846 (USEPA 1995) and is described in detail in Denton *et al.* (2001).

Principal Findings and Significance

All nearshore sediments revealed some degree of impaction (Table 1). Iron was consistently the most abundant element encountered while Ag was not detected in any sample analyzed. Nearshore sediment samples generally yielded higher metal levels than their offshore counterparts (Fig 2-3). This was particularly true for Cu, Pb and Zn, three of the most common anthropogenic metal contaminants associated with urban runoff (Makepeace *et al*. 1995).

Table 1: Heavy Metals in Surface Sediments from the Southern Half of Saipan Lagoon as a Function of Distance from Shore – Pooled Data

Distance (m)	Statistic[1]	Heavy Metal Concentrations (µg/g dry weight)[2]									
		Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
0	Range	all <0.20	<0.19 - 0.79	1.72 - 8.28	0.59 - 50.7	82.9 - 6,664	3.57 - 80.5	2.38 - 364	0.38 - 6.23	0.39 - 31.0	2.75 - 98.5
N=16	Mean	nc	nc	4.13	2.87	660	13.7	19.3	0.65	3.67	11.5
10	Range	all <0.20	<0.19 - 0.40	1.27 - 10.2	0.20 - 53.8	57.0 - 4,077	0.59 -103	2.38 - 81.5	0.38 - 3.53	0.39 - 45.2	0.39 -82.0
N=48	Mean	nc	nc	3.89	1.25	430	6.82	11.7	0.50	2.38	5.12
25	Range	all <0.20	<0.19 - 0.60	2.00 - 9.36	0.20 - 16.5	61.8 - 4,437	0.59 - 79.1	2.58 92.6	0.38 - 3.53	0.39 - 45.7	0.20 - 67.6
N=48	Mean	nc	nc	4.10	1.3	446	11.3	12.9	0.49	1.79	3.8
50	Range	all <0.20	all <0.20	2.59 - 7.35	0.19 - 6.51	50.3 - 2,840	2.38 - 59.7	2.19 - 67.1	0.38 - 2.71	0.39 - 7.11	0.19 -18.8
N=48	Mean	nc	nc	3.83	0.76	384	10.2	11.1	0.52	0.74	1.76
100	Range	all <0.20	all <0.20	2.04 - 5.12	<0.20 -2.94	50.0 - 1,221	1.15 -130	2.35 - 39.9	0.38 - 1.57	0.39 - 4.80	<0.19 - 7.45
N=48	Mean	nc	nc	3.47	0.51	259	7.1	10.1	0.43	0.52	0.68
250	Range	all <0.20	all <0.20	1.85 - 3.86	<0.19 - 6.47	31.0 - 300	1.20 - 100	1.38 - 31.2	all <0.40	0.39 - 2.80	<0.19 - 3.40
N=48	Mean	nc	nc	2.93	0.25	102	6.5	4.30	nc	0.44	0.34
500	Range	all <0.20	all <0.20	1.82 - 3.24	<0.19 - 0.40	22.9 - 127	0.71 - 55.8	0.99 - 7.75	all <0.40	all <0.40	<0.19 - 0.40
N=39	Mean	nc	nc	2.58	0.22	57.1	5.54	1.90	nc	nc	0.21
1000	Range	all <0.20	all <0.20	1.48 - 3.39	all <0.20	21.0 - 62.6	0.56 - 13.4	1.18 - 7.55	all <0.40	all <0.40	<0.19 - 0.40
N=21	Mean	nc	nc	2.26	nc	46.0	1.71	1.98	nc	nc	nc
		Typical Ranges Found Clean in Cabonate Sands[3]									
Nearshore (<250 m offshore):		<0.1	<0.1	1-5	1-3	50-500	5-10	10-50	1-3	<1	3-5
Offshore (≥250 m offshore):		<0.1	<0.1	1-3	<0.1	20-100	1-5	1-10	<0.2	<1	<1

[1] Mean as geometric mean; [2] Hg data as ng/g dry weight, [3] Denton *et al.* 2001; nc = not calculable

Metal concentrations in surface sediments often varied considerably within and between sites equidistant to the shore. Sediment heterogeneity associated with the patchy distribution of seagrass beds (*Enhalus acoroides*) in nearshore waters and the muddy substrates contained therein, accounted for at least some of this variability. Overall, levels of Cu, Cr, Ni, Pb, and Zn were strongly correlated with those for Fe (correlation coefficients: 0.605-0.878). In contrast, Hg concentrations did not correlate well with any other metal examined (correlation coefficients: 0.132-0.279).

Degree of Contamination

According to the numerical guidelines for classifying metal contaminants in carbonaceous sediments of biogenic origin (Denton *et al.* 1997), the highest levels of each element encountered

fell into the '*lightly contaminated*' category for Cr and Ni; the '*moderately contaminated*' category for Cd, Pb, Hg and Zn, and the '*heavily contaminated*' category for Cu. Sites exhibiting the greatest degree of enrichment for these elements were found on transect lines extending from storm drains 3, 4 and 11 for Zn and Cd; drain 22 for, Zn, Cu, and Pb; drains 1, 3 and 11 for Cu, Cr, and Ni respectively, and drains 7 and 9 for Hg. The highest levels were mostly found in sediments no more than 25 m offshore which clearly implicates urban runoff from adjacent roads, residential areas and commercial premises as the primary means of input

Additional metal contributions from on-site sources such as the small boat launching facility near storm drain 3 and residual solid waste components that remain buried in Chalan Kanoa Lagoon in the vicinity of storm drain 22 also emerged from this investigation. Sedimentary Pb levels recorded at the latter location were consistently high and ranged from 30.2-45.7 µg/g up to 25 m offshore. Beyond that, mean levels attenuated markedly to 6.5 µg/g, 4.0 µg/g and 2.4 µg/g at 50 m, 100m and 250 m offshore respectively. Lead levels in clean coral sands rarely exceed 0.5 µg/g (Denton *et al*. 1997, 2006). Clearly, there is significant and widespread Pb contamination in this particular portion of Saipan Lagoon. Suspected sources of contamination include munitions left over from WWII and old car batteries.

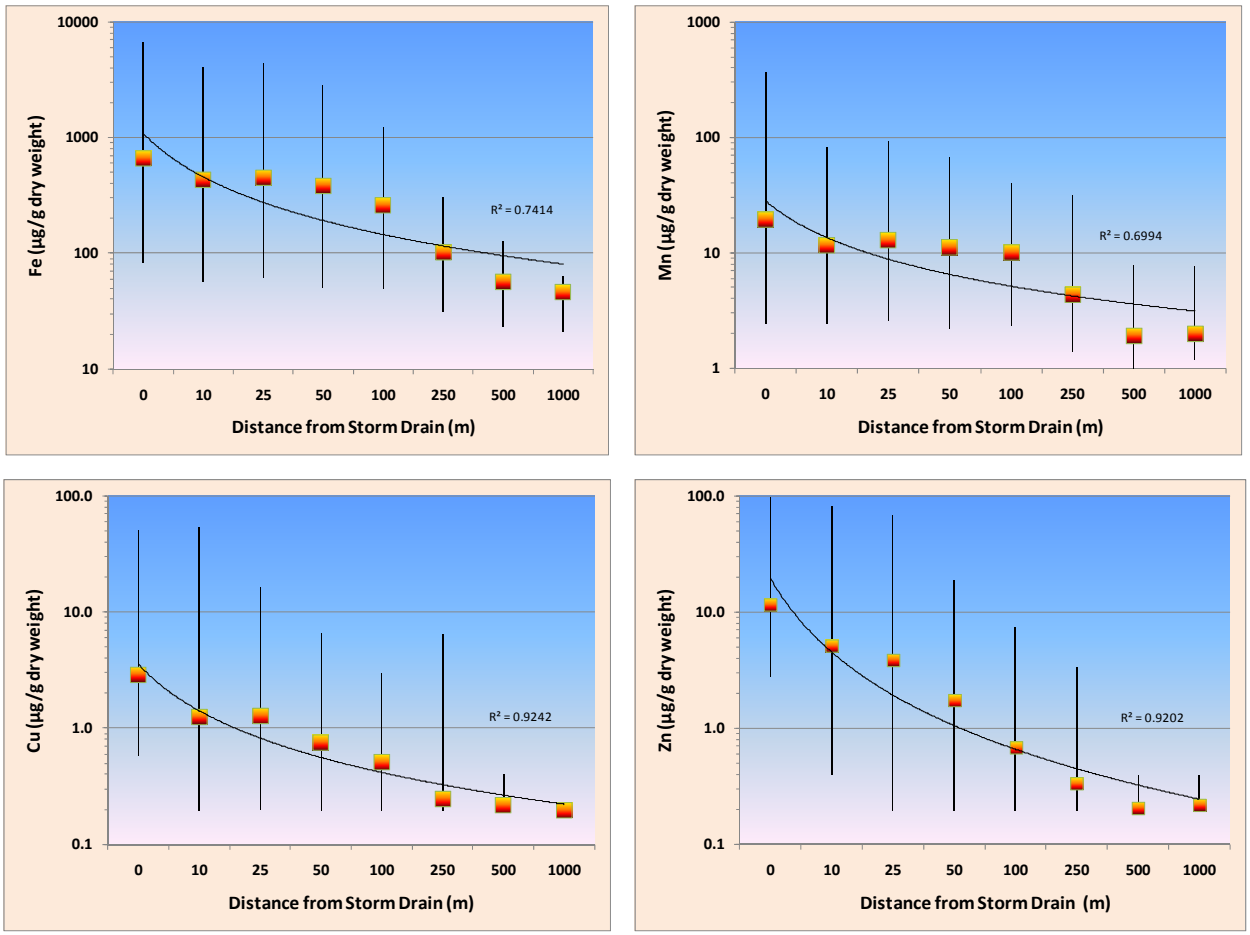

Figure 2: Relationship between metal concentrations in surface sediments and seaward distance from shoreline storm water discharge points in the southern half of Saipan Lagoon. Data are geometric means and ranges for each element shown.

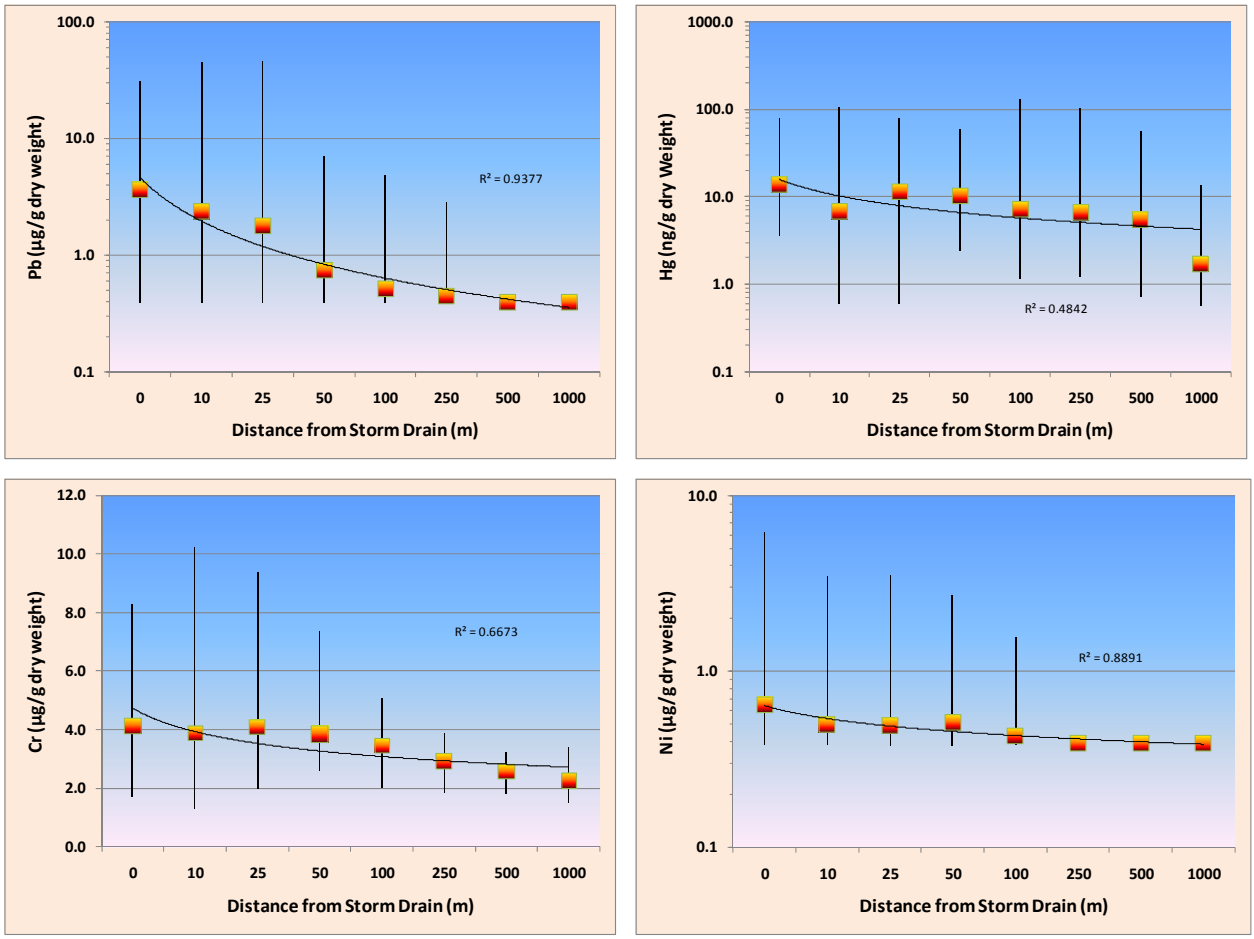

Figure 3: Relationship between metal concentrations in surface sediments and seaward distance from shoreline storm water discharge points in the southern half of Saipan Lagoon. Data are geometric means and ranges for each element shown.

Another surprising outcome of this study was the discovery of relatively high Hg levels in offshore sediments out from storm drain 7 and 9. The source of Hg in this region, though clearly significant, is currently unknown. Quite possibly there is an on-site source associated with the allied invasion during WWII. Alternatively, it could be the result of Hg enriched runoff entering the lagoon at storm drain 9 and moving seawards in a northerly direction (Fig. 4)

Biological Effects

The numerical sediment quality guidelines developed by MacDonald *et al.* (1996) provide a useful means of determining possible adverse biological effects to organisms inhabiting contaminated sediments. Using their criteria, no *Probable Effects Level* (PEL) exceedences were encountered for any metal examined. However, the *Threshhold Effects Level* (TEL) for Cd (0.68 µg/g) was approached in nearshore sediments out from storm drains 3 (0.6 µg/g) and 4 (0.59 µg/g), and exceeded in beach sand by storm drain 11 (0.79 µg/g). The Cu TEL (18.7 µg/g) was exceeded in beach deposits close to storm drains 1 (50.7 µg/g), 3 (32.4 µg/g) and 11 (19.5 µg/g), and in nearshore sediments out from storm drain 22 (53.8 µg/g). The TEL for Pb (30.2 µg/g) was also exceeded in beach sand (31.0 µg/g) and nearshore sediments (45.7 µg/g) down gradient of the latter discharge point. Only maximum values recorded are given in each case. There were

no TEL exceedences for any other metal examined although that for Hg (130 ng/g) was matched in an offshore sample collected 100 m out from storm drain 7 and approached in another (100 ng/g) taken at the 250-m mark along the same transect. A similar value of 103 ng/g was recorded in a sediment sample taken 10 m out from storm drain 9.

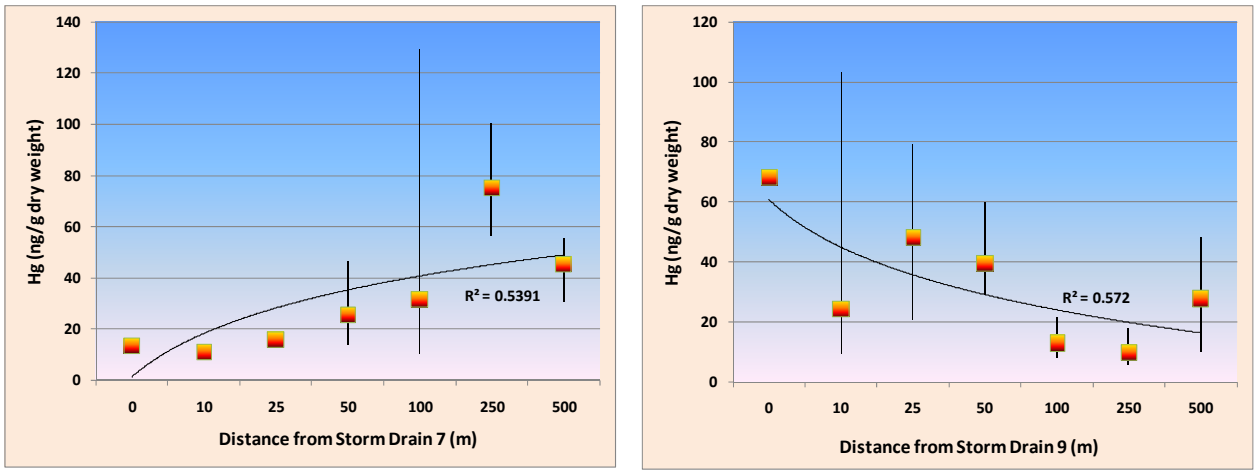

Figure 4: Relationship between mercury levels in surface sediments and seaward distance from storm drains 7 and 9 in the southern half of Saipan Lagoon. Data are geometric means and ranges

Studies to determine the potential impact of these hot-spots on the edible quality of resident bivalves and other fisheries resources in the area are ongoing. Some preliminary data are presented here for Pb and Cu levels in *Atactadea striata* and *Gafrarium pectinatum*, two dominant intertidal bivalves collected down gradient of various storm drains in the study area (Fig. 5). Neither bivalve was found at all discharge points.

The data reveal that the Cu and Pb contamination noted in sediments near storm drain 22 is reflected in the tissue of both bivalves. These findings are important considering that both species are popularly harvested for food by local residents. While no enforceable USA standard exists for Cu and Pb levels in shellfish, the standard in effect for Cu in other countries ranges from 10-100 µg/g wet weight (Nauen 1983). This suggests that the maximum Cu levels reported here in both bivalves are of no consequence from a human heal perspective. Unfortunately, the same cannot be said of Pb.

The U.S. Food and Drug Administration (FDA) currently advocates a non-enforceable guideline for Pb in shellfish of 1.7 µg/g wet weight, or about 10 µg/g dry weight. This value is closely approached by those found in *A. striata* taken near storm drain 22 and greatly exceeded by *G. pectinatum* from the same area. The appropriate Saipan authorities have been notified of this finding with the recommendation that a health advisory should be posted to warn those who harvest bivalves for food in this part of Saipan Lagoon.

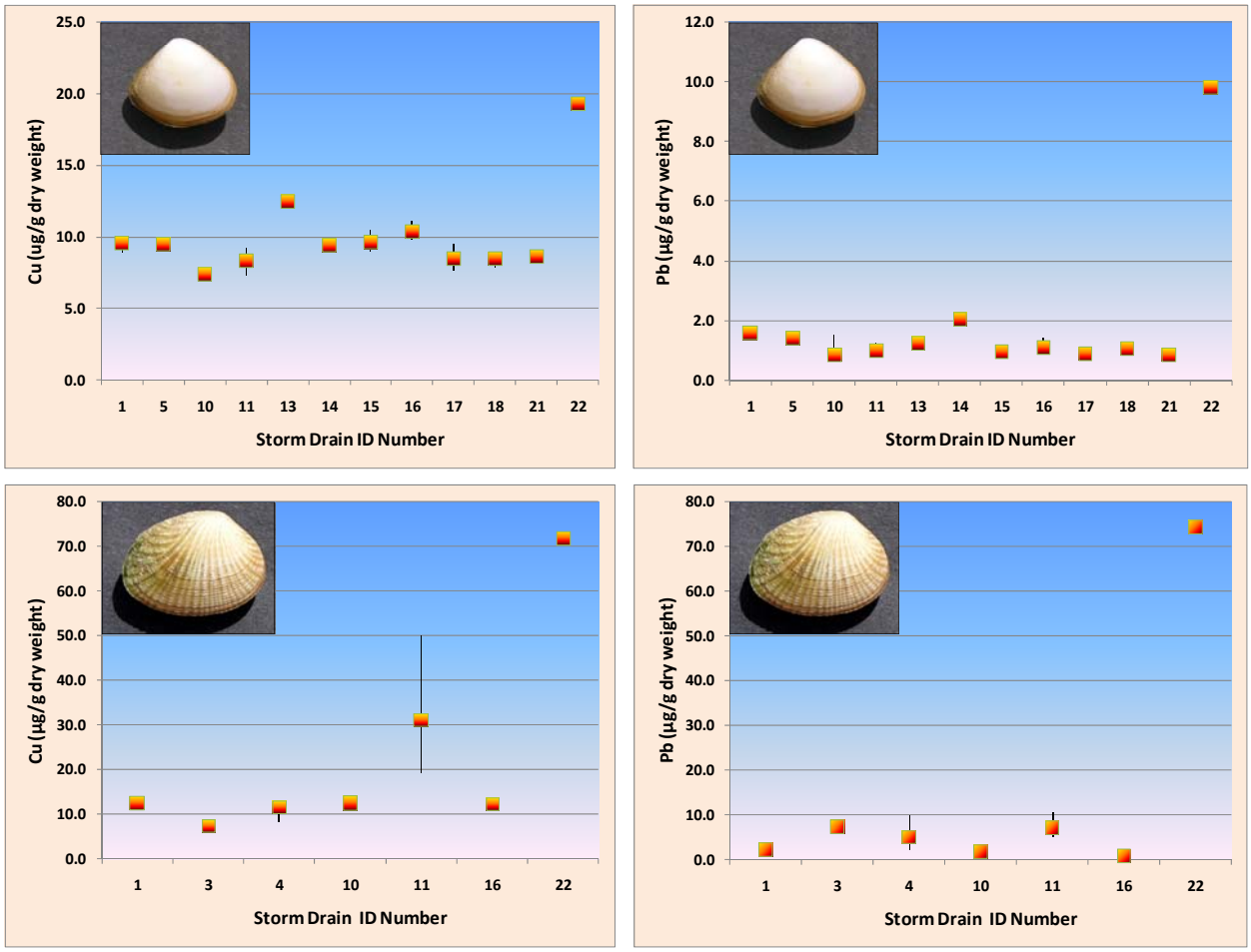

Figure 5: Copper and Pb in intertidal bivalves, *Atactodea striata* (upper L and R) and *Gafrarium pectinatum* (lower L and R), taken immediately down gradient of stormwater discharge points along the southern half of Saipan Lagoon

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Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM

Basic Information

Title:	Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM
Project Number:	2009GU164B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Use
Descriptors:	Hydropower, Flow Duration Curves, Streams
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publication

1. Heitz Leroy, and Shahram Khosrowpanah, 2010, Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM. Water and Environmental Research Institute (WERI), University of Guam, Mangilao, Guam, Report No. 129, 26 pp, in press.

PROJECT SYNOPSIS REPORT

Project Title: Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM

Problem and Research Objectives

The cost and availability of energy resources is one key factor in the economic development and quality of life in any developing country. This is especially true in Pohnpei, Federated States of Micronesia (FSM), where nearly all of the energy produced is from costly, non-renewable, and potentially environmentally damaging fossil fuel (oil) resources. The cost of fuel to operate the local power plant has risen dramatically over the past years and no doubt will continue to rise in the future. With these increases of fuel costs, it becomes more and more important to explore other means of providing energy to the island's power grid.

Pohnpei is blessed with an abundance of surface water resources and because of the extreme topography of the island many of these streams have very high slopes. This combination of abundant streamflow and high stream gradient or slope is ideal for the application of run-of-river-hydropower development. This kind of hydropower development has the least environmental impact and is generally less capital intensive than typical hydropower plants built in conjunction with high dams with large amounts of water storage.

In order to explore the feasibility of using hydropower as an additional energy source for Pohnpei, it is necessary to be able to define the variability of flow available in the streams where the hydropower plants might be constructed. This is normally done by direct analyses of streamflow data for the stream in question or by applying some sort of inferential techniques from a gaged to an ungaged streams or from a gaged location on a stream to an ungaged location on that same stream. Of course, the most reliable means is to use actual stream flow data measured at the point of interest. The problem in Pohnpei, as in most locations, is that stream flow information is not available for all possible sites where development could occur. In the FSM this problem is even more acute since the streamflow gaging network has been abandoned for almost 30 years. The overall objective of this project is develop flow durations curves for reaches of Pohnpei's streams. These flow duration curves will be essential for studying future hydropower development in the streams. It will also be useful in making studies of low flow requirements and availability of water for various surface water developments and the study of the impacts of mans activities on stream flows. The project's goals were: to develop flow duration curves for all of the previously gaged stream sites in Pohnpei, to apply techniques for transferring the flow duration curve information available at the gaged locations to ungaged sites, divide Pohnpei's streams into homogenous stream reaches with similar flow characteristics, to develop flow duration tables and curves for each stream reach, to develop a set of GIS based maps showing the location of all stream reaches, and finally to provide sample calculations of power potential and economic feasibility of several potential hydropower sites on Pohnpei.

Methodology

This project was divided into several phases that are described below.

PHASE I, Develop Flow Duration Curves for Each Gage Site

The first step was to gather all the available daily streamflow data for Pohnpei's streams into computer spreadsheet form. This was accomplished using the Water and Environmental Research Institute's (WERI's) Earth Info CD-ROM data base and accompanying data accessing programs. Figure 1 shows the location of the United States Geological Survey (USGS) stream gage sites that were used in the study. Figure 2 provides information on the period of record for each of the gages.

A spreadsheet program developed specifically for use on this project assigned each of the daily flows into flow range categories specified by the user. The number of daily flow values greater than or equal to the upper limit of each category was then calculated. This value was divided by the total number of flows to find the percent of daily flows greater than or equal to the highest flow in that category. This term is called the exceedance percentage. A flow duration curve that shows the flow versus the exceedance percentage was plotted for all Pohnpei's gage sites as shown in Figure 3.

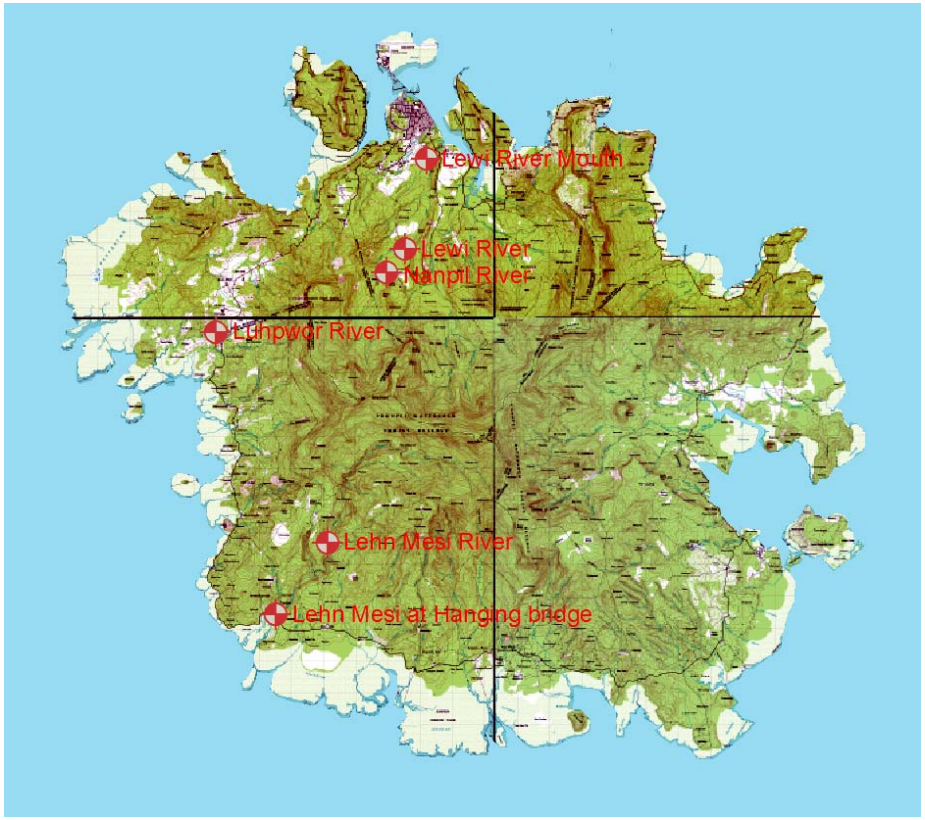

Figure 1. Location of USGS stream gage sites

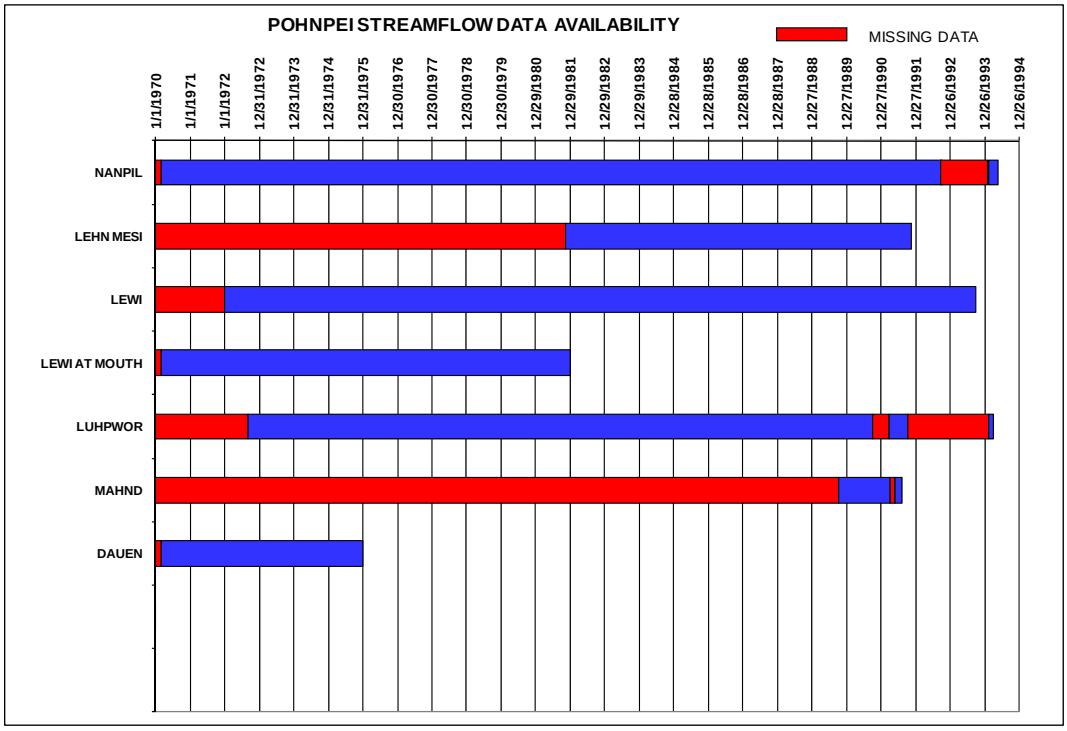

Figure 2. Availability of stream flow data from USGS gages on Pohnpei

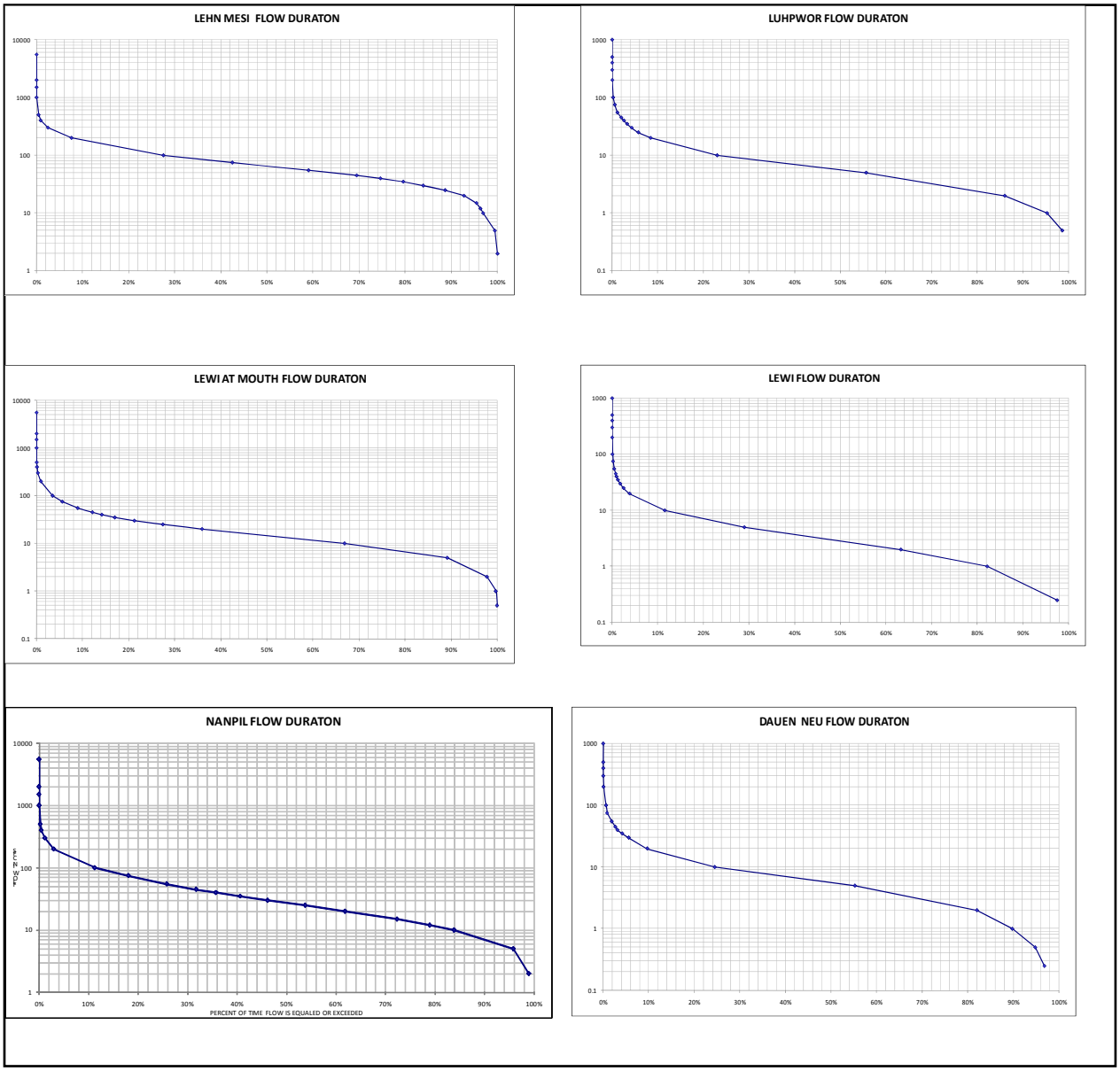

Figure 3. Duration Curves for Nanpil, Lehn Mesi, Luhpwor, Lewi at Mouth, Lewi, and Dauen Neu Rivers

PHASE II, Prediction of Duration Curves at Ungaged Sites

Phase II involved the application of a technique to predict duration curves at ungaged sites in Pohnpei. This step is important because many of the potential hydropower sites in Pohnpei are not located at or near stream gage locations. Some may be located upstream or downstream from gagged location and some may be located on streams where no previous stream flow records are available. The method that was applied involved the development of parametric curves of flow versus average annual flow for chosen specific exceedance percents. This method was originally developed by the co-

investigator in a study of hydropower potential in the Pacific Northwest. (Gladwell, et al, 1979).

The first step in applying the method was to take the flow values for the key exceedance percentages of Q(95), Q(30), Q(50), and Q(30) from each of the duration curves developed in Phase I. These particular exceedance values were chosen because these percentages are important in the sizing of hydropower plants. Next the average annual flow was computed for each site. The values of Q vs Average Annual Flow were plotted for each exceedance value at each site and a best fit curve was matched to the data sets. The resulting parametric curve is shown in Figure 4.

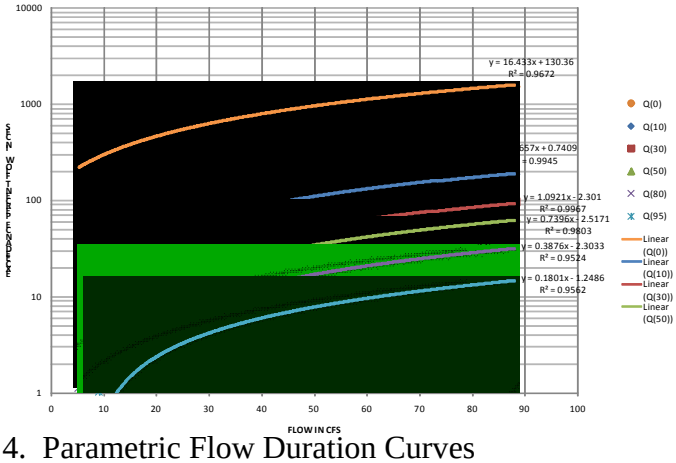

Figure 4. Parametric Flow Duration Curves

The best fit equations are shown at the end of the curves for each exceedance percentage. Although there were limited number of data points the high R^2 values indicates a very good fit to the data by the prediction equations. These equations were used later to predict actual flows at ungaged sites or stream reaches. Figure 5 shows an example of using the ungaged curves to predict the flow duration cure values for an ungaged site with an average annual flow of 60 cfs.

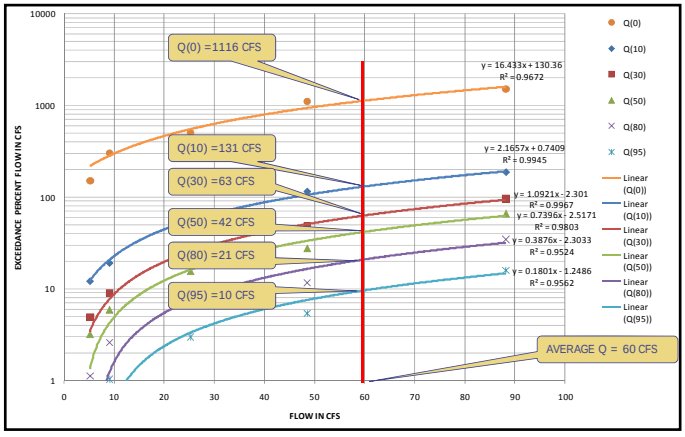

Figure 5. Use of parametric flow duration curves to predict flow duration values at an ungaged site with an average flow of 60 cfs

PHASE III, Develop a Means to Predict Average Flow at Ungaged Points on Streams

In Phase III we developed a means to predict average flows at ungaged points on Pohnpei's streams. The technique called for the development of grid based maps of elevations and average annual rainfall and then applying various GIS Watershed functions available in the computer program ArcMap. The end product was a grid based map of average rainfall input for the streams in Pohnpei. Since, not all the rainfall reaches the stream due to the losses in the hydrologic system; a correction factor called "Runoff Factor, RF" was employed. The RF factor was developed for gaged streams as shown in Figure 6. A best fit curve was developed as shown so that runoff factors at ungaged sites could be predicted. These factors were multiplied by the GIS predicted rainfall input to determine the average annual flow for ungaged locations. Next the predicted average flow for ungaged sites were inputted into the parametric flow duration curves (Figure 4) in order to predict flow duration curves for ungaged sites. More detail on procedure is reported in (Heitz, Khosrowpanah, 2010).

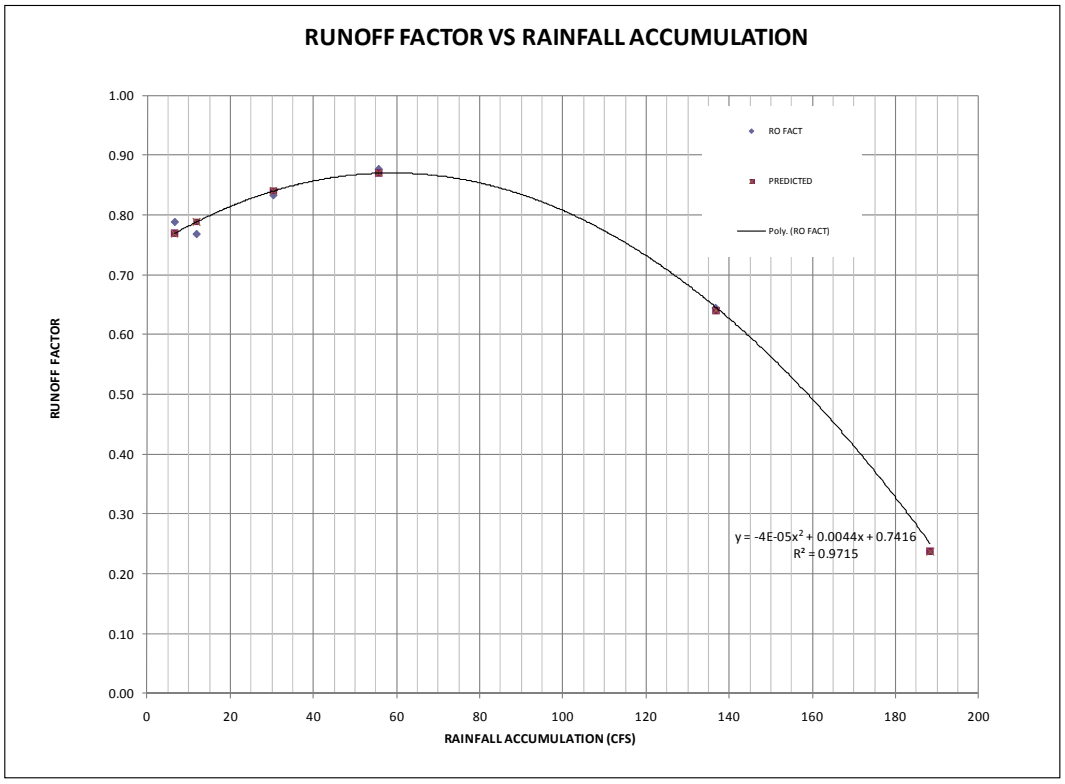

Figure 6. Runoff factor vs rainfall accumulation

PHASE IV, Stream Reach Delineation and Average Flow

In Phase IV we divided Pohnpei's streams into homogenous stream reaches with similar flow characteristics (small pieces of watershed that contributes to each tributary of the major stream within the watershed). This mapping was done starting with the USGS's Digital Line Graphics (DLG) hydro-coverage available for the USGS Topographic Maps. Substantial editing was required on the Hydro DLGs to develop a good coverage showing

only the streams. Figure 7 shows an actual stream reach on the Lehn Mesi River as an example.

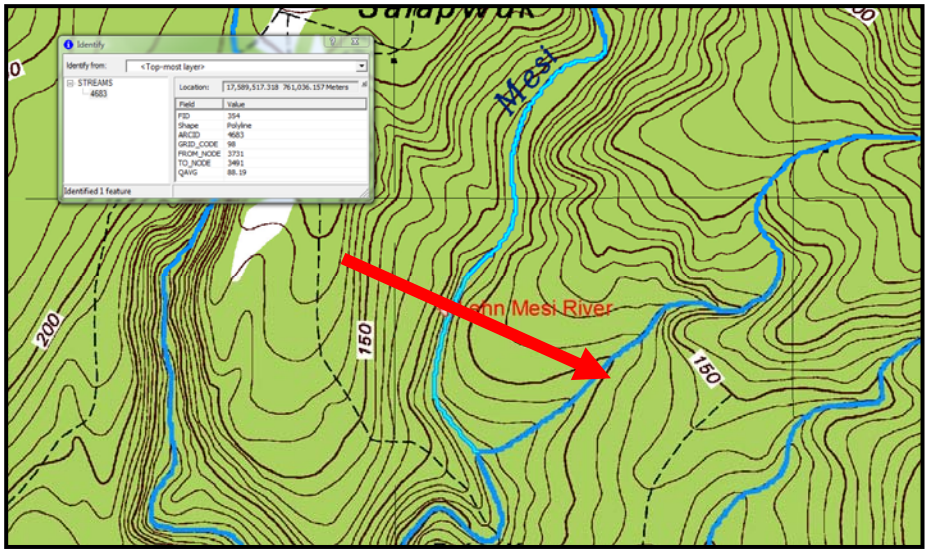

Figure 7. Individual stream reach on the Lehn Mesi River

PHASE V, Hydro Power Production and Economic Analysis

In this Phase of the work a means of calculating the power potential and economic feasibility of potential hydropower sites in Pohnpei was developed. A previously developed spreadsheet program (Heitz, 1982) was used as a basis for the new hydro power potential Excel application. The first worksheet of the application is shown in Figure 8. Input to this sheet is the potential site's average annual flow which comes from the previously described GIS maps. The application computes the flow duration values using the parametric duration curves described earlier. The application also plots the flow duration curve for the selected site. The second worksheet of the application, shown in Figure 9, computes the power production and economics of the site based on the flow duration curves computed on the first worksheet and the input site head, turbine sizing information and economic considerations. This application will allow the user to explore various turbine sizing and economic considerations to determine the preliminary feasibility of developing a hydropower facility at a particular site. A copy of the Excel Workbook will be furnished to those interested in carrying out their own analysis at other sites in Pohnpei.

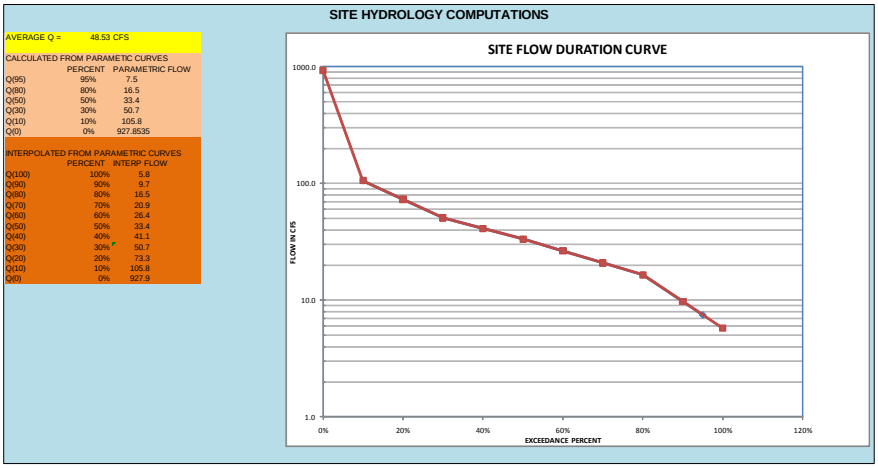

Figure 8. Hydrology worksheet of hydropower analysis application

TURBINE SIZING RECONNAISSANCE PACKAGE
BY DR. LEROY HEITZ P.E.

TURBINE PARAMETERS

	DESIGN	MINIMUM	MAX EFF (%)
Q TURBINE 1=	4	3.2	0.83
Q TURBINE 2=	4	3.2	0.83
Q TURBINE 3=	4	3.2	0.83
GENERATOR EFFICIENCY=	0.9		

	FLOW RATIO	EFFICIENCY RATIO
1.	0	0
2.	0.6	0.7
3.	0.8	0.8
4.	0.9	0.95
5.	1	1

OTHER DESIGN PARMETERS

COMPUTATIONAL PERIOD =	365	DAYS
PENSTOCK LENGTH =	8000	FT
STREAM MINIMUM Q =	1	CFS

AVAILABLE FLOW AND HEAD / **POWER PRODUCTION**

EXCEED	STREAM FLOW	GROSS HEAD	AVAIL FLOW	FLOW TURBINE 1	FLOW TURBINE 2	FLOW TURBINE 3	FLOW UNUSED	POWER TURBINE 1	POWER TURBINE 2	POWER TURBINE 3	POWER TOTAL	ENERGY TOTAL
%	CFS	FT	CFS	CFS	CFS	CFS	CFS	KW	KW	KW	KW	MWH
100	2.00	800.00	1.00	0.00	0.00	0.00	1.00	0	0	0	0	
90	3.50	800.00	2.50	0.00	0.00	0.00	2.50	0	0	0	0	0.00
80	4.50	800.00	3.50	3.50	0.00	0.00	0.00	142	0	0	142	62.03
70	6.00	800.00	5.00	4.00	0.00	0.00	1.00	192	0	0	192	146.22
60	8.00	800.00	7.00	4.00	0.00	0.00	3.00	192	0	0	192	168.37
50	10.50	800.00	9.50	4.00	4.00	0.00	1.50	192	192	0	384	252.55
40	15.00	800.00	14.00	4.00	4.00	4.00	2.00	192	192	192	577	420.92
30	22.00	800.00	21.00	4.00	4.00	4.00	9.00	192	192	192	577	505.11
20	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
10	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
0	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
											SUM E =	3070.54

ECONOMICS COMPUTATIONS

ECONOMIC INPUTS

COST TURBINE 1 =	$1,000	$/KW	BORROWING PERIOD =	30	YRS
COST TURBINE 2 =	$1,000	$/KW	INTEREST RATE =	12	%
COST TURBINE 3 =	$1,000	$/KW	CONSTRUCTION PERIOD =	1	YRS
PENSTOCK COST =	$100	$/FT	TAXES =	3.5	% 1st COST
OTHER COSTS =	$50,000	$	INSURANCE =	0.15	% 1st COST
ENERGY VALUE =	$0.10	$/KWH			
CAPACITY BENEFIT=	$100	$/KW			

ECONOMICS RESULTS

FIRST COSTS		ANNUAL COSTS		ANNUAL BENEFITS	
TURBINE COST =	$606,957	INTEREST AND PRINCIPLE=	191,724	ENERGY BENEFIT =	$307,054
PENSTOCK COST =	$800,000	TAX COST =	50,994		
OTHER COST COST =	$50,000	INSURANCE COST =	2,185	CAPACITY BENEFIT =	$60,696
CONSTRUCTION INTEREST =	$87,417	O&M COST =	13,115		
TOTAL COST =	$1,544,375	TOTAL ANNUAL COST =	258,019	TOTAL NET ANNUAL BENEFIT =	$367,749
ANNUAL COST =	$191,724			NET BENEFITS =	$109,731
				B/C =	1.425

Figure 9. Hydropower output, turbine sizing and economic feasibility worksheet of hydropower analysis application

Principal Findings and Significance

This study provided a means to evaluate the hydroelectric potential at sites and on reaches of streams in Pohnpei, FSM. In order to accomplish this, average flows were developed for stream reaches on all Pohnpei's major streams. A means of computing flow duration curves from these average flows was also developed.

A spreadsheet application is provided in which average flows are input along with various hydraulic and economics parameters. A power potential and economic analysis is then performed. This analysis provides preliminary estimates of the feasibility of developing a hydroelectric project at a particular site. The spreadsheet is available as part of the data package for this project.

The average flow data is made available through a GIS map of the stream reaches on all the major streams on Pohnpei. The data for this map is available for use with the free GIS application Arc Explorer. This average flow data is useful for other applications beyond just estimating hydroelectric potential. When coupled with the hydrology worksheet in the spreadsheet application, flow duration curves can be estimated for any stream in Pohnpei. This information could be used for in stream flow requirement studies or other studies investigating man impact on the natural flow patterns in the streams.

LITERATURE CITED

Gladwell, J.S., L.F. Heitz, C.C. Warnick, C.C. Lomax, P.C. Klingeman, & A.B. Cunningham. “A Resource Survey of Low-Head Hydroelectric Potential at Existing Dams and Proposed Sites in the Pacific Northwest Region, Phase II”, University of Idaho Water Resources Research Institute, Report No. (197905), 1979.

Heitz, L.F. “Hydrologic Analysis Programs for Programmable Calculators and Digital Computers for Use in Hydropower Studies”, University of Idaho Water Resources Research Institute, Report No (198207), 1982, 127 pages.

Heitz, L.F.and S. Khosrowpanah. “Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM”. University of Guam/WERI, Technical Report No. 129, 2010, 30pages, in printing.

Khosrowpanah, S, and Mark Lander, and L. Heitz, “Pohnpei-the wettest island on earth? Tools for managing watershed”, Proceeding of the Institutions for sustainable watershed management, American Water Resources Association, Honolulu, Hawaii, June 27-29, 2005.

Information Transfer Program Introduction

WERI's research activities focus predominantly on local water resources problems and issues identified largely through discussions with regional stakeholders at our annual advisory council meetings. Disseminating the results of these investigations to appropriate governmental agencies, environmental managers, policy makers and other local decision makers in the water resources business, has the highest priority and is accomplished in various ways. Institutional technical reports remain a strong vehicle for transmitting such information to our target audiences, many of whom are remotely situated and do not have access to the scientific literature, or require a greater degree of detail than is normally permissible in a standard journal publication. Our recently developed website is also gaining popularity among professional circles, both at home and abroad, and is now accessible to the great majority of our stakeholders throughout the region. We remain strong in our commitment to teaching and training the up-and-coming water resources professionals of tomorrow, in addition to conducting workshops, courses and seminars for those currently employed in this area. WERI faculty also continue to be major and effective participants in law and policy making on Guam by serving as committee members and chairs on numerous governmental boards and by giving testimony at legislative oversight hearings.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2009GU148B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	Information Transfer, Education, Water Resources
Principal Investigators:	Gary Denton

Publications

There are no publications.

WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such as brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied geographically and by education level. It is important that WERI make this information available in a very widely distributed form.

The WERI web-site is the Institute's primary Information Transfer/Dissemination mechanism. . This year's Information Transfer Project funded a significant improvement of the site in both format and design. The new home page, shown below, is located at http://www.weriguam.org/. It features informational links to WERI faculty, staff and Institutional facilities, our current research, education and train activities, primary sponsors and most recent publications. The new format is intended to increase visibility to the Institute's research programs and research projects underway in each. It is also intended to simplify the site and make it more user friendly particularly for our stakeholders in remote locations where state-of-the-art internet services and computer technology are often lacking

WERI Web-site Home Page

This project also funded the design, layout and printing of three (3) major technical completion reports resulting from USGS funded research projects. One hundred (100) hard copies of each report were printed. All WERI technical completion reports are available in downloadable pdf format on the WERI web-site at http://www.weriguam.org/reports/list.

The technical completion report library was brought up to date with the inclusion of several new additions and a number of older volumes that were previously missing. We have upgraded the

data base search engine process for accessing these reports on line. To this end, an 'Abstract' data base is used for key word searches, and searches based on 'Author' will search all authors in the author string not just the lead author as before. Upon selection of a particular report, site users are presented with the complete abstract, which may be viewed prior to downloading the main report. An example is shown below.

WERI Reports Page

Because of Guam's remote location, and the escalating costs of air travel, it is difficult and costly for researchers to present their findings at technical conferences and symposiums in other parts of the Globe. A portion of the current Information Transfer Project was earmarked for off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past 104-B research projects.

Information Management

Basic Information

Title:	Information Management
Project Number:	2009GU150B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Hydrology, Management and Planning
Descriptors:	Rainfall Data, Climate, Water Resources Management
Principal Investigators:	Gary Denton

Publications

There are no publications.

INFORMATION MANAGEMENT

WERI's mission involves maintaining and providing water resources related data to researchers, water resources managers, educators and the general population of the islands of the Western Pacific. This project was used to provide funding to maintain subscriptions to a wide variety of data sources dealing with meteorology, climatology and hydrologic data. These resources are maintained at WERI and made available to researchers, water managers, educators and the general public throughout the region. Communication and information exchange between experts in the area of water resources is vital to the improvements in the wise use of this resource.

Protect Guam's Fresh Water: Taking Personal Responsibility for Pollution, Conservation and Community Action

Basic Information

Title:	Protect Guam's Fresh Water: Taking Personal Responsibility for Pollution, Conservation and Community Action
Project Number:	2009GU151B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Conservation
Descriptors:	Water Resources, Freshwater, Groundwater, Aquifer, Surface Water, Watershed, Non-point Source Pollution, Conservation, Runoff, Stormwater Overflow
Principal Investigators:	Arretta Ann Card, John Jenson

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Protect Guam's Fresh Water: Taking Personal Responsibility for Pollution, Conservation and Community Action.

Problem and Research Objectives

Fresh water is one of Guam's premier natural resources. Ground water and surface water sources supply the fresh water that is vital to life on our island. All households and businesses in our communities rely on fresh water for daily consumption and activities. Beyond drinking, washing and the daily activities of life, we must have a reliable and amply source of clean water to support our industries (including tourism), to preserve community health, to control fires, and for recreation. A stable supply of fresh water improves property values and is essential to the island's economy. Guam residents must have access to information about the value of our freshwater supply if they are to take responsibility for curtailing pollution originating in households and businesses, conserving water through consumer-side system maintenance and water saving practices, and participating in community action and decision-making.

Methodology

This education program was designed to create an awareness and interest in public policies that support the protection of clean and abundant fresh water on Guam and to encourage personal practices that do likewise. The focus is on providing easy access to information about taking responsibility for both personal actions and community decisions. The campaign, Protect Guam's Fresh Water/*Prutehi i Hanom* Freskon Guahan, is targeted to adult residents of Guam especially home owners or household managers, residents with septic tanks, business owners/directors, farmers and those who must dispose of household-type chemicals at home or work.

The program is presented on a website located at www.ProtectGuamsFreshWater.com. The website includes: (1) A Public Service Campaign featuring downloadable print, radio and television announcements suitable for use by local media; (2) An Online 'Clearinghouse' consisting of a growing Directory and Registry of businesses, agencies, public officials, volunteer groups and concerned individuals who are engaged in community activities that create positive outcomes for fresh water resources as well as the other natural resources of our island. Entities may share their ongoing activities, volunteer opportunities, mission statements, and contact information; and (3) Two Information Sections, "Household Pollution" and "Water Conservation," which emphasize simple, everyday habits for avoid polluting freshwater resources when disposing of household chemicals and practicing water conservation at home that take into consideration local lifestyles and conditions.

Principal Findings and Significance

Guam residents now have easy 24/7 access to information about protecting Guam's fresh water supply, taking personal responsibility for controlling pollution from household-type chemicals, landscaping/farming activities, and septic tanks, conserving water by repairing

consumer-side water leaks, instituting water saving practices; and participating in decision-making and community discussions.

Public agencies and officials, businesses, nonprofit and volunteer organizations and concerned individuals now have a central registry and directory to share their activities, mission focus, contact information, specific activities and needs for volunteers. Members of the public have a central location to access this information and act in what they consider to be the best interests of protecting Guam's fresh water resources and other natural resources and related environmental issues.

Protect Guam's Fresh Water/*Prutehi i Hanom Freskon Guahan*, (located at www.ProtectGuamsFreshWater.com) is an ongoing reminder of the value and importance of the island's natural resource of fresh water.

Figures 1-7 follow below.

Figure 1. Home page of www.ProtectGuamsFreshWater.com

Magazine ad – 1/2 pg. Full Color

Magazine ad – 1/4 pg. Full Color

Newspaper ad – Full color 2 col. X 2"

Figure 2. Public Service print ads

Protect Guam's Fresh Water

Prutehi i Hanom Freskon Guahan

Taking Personal Responsibility for Pollution, Conservation and Community Action

A project of WERI

Home | Directory | Register | Public Service Materials

Household Pollution

Water Conservation

Community Action

Learn more as a family.
Visit GuamWaterKids.com

Whatever we dump in our yards, roadsides, drains, septic systems, and trash can get into our fresh water supply.

HOUSEHOLD CHEMICALS: Leftover automotive oil, paint, pesticides, fertilizers, solvents and other household hazards can pollute our fresh water supply.

- Buy only the amount you need and use all or as much as possible before disposing the left overs.
- If the product goes down the drain in normal use, then it's okay to dilute with water and pour it down the drain.
- Never mix chemicals together before disposing of them.
- Don't "hide" your hazardous household waste in your regular trash pickup.

LANDSCAPING AND GARDENING: Gardening, farming and cutting back the boonies can impact our fresh water supply

- Buy only the amount you need and use all or as much as possible before disposing the left overs.
- If the product goes down the drain in normal use, then it's okay to dilute with water and pour it down the drain.
- Never mix chemicals together before disposing of them.
- Don't "hide" your hazardous household waste in your regular trash pickup.

SEPTIC SYSTEMS: Here are some considerations if you home is one of the many on Guam that relies on a septic system to dispose o sewage.

- When working properly, septic systems remove most of the pollutants of household wastewater including nitrogen, phosphorus, bacteria and viruses.
- Protect our island's freshwater supply by having your septic tank pumped every 3-5 years. In the long run, pumping saves money because without regular maintenance you might have to replace your whole septic system.
- Conserve water with the tips in the next section so your septic tank doesn't have to handle so much wastewater.
- Consider hooking up to the water utility system for sewage disposal. In the future, homeowners whose property can be served by utility sewage lines may be required to tie into the community system.

WERI

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Funded by the US Geological Survey. Site by Card & Card Advertising.

Figure 3. Household Pollution Information web page

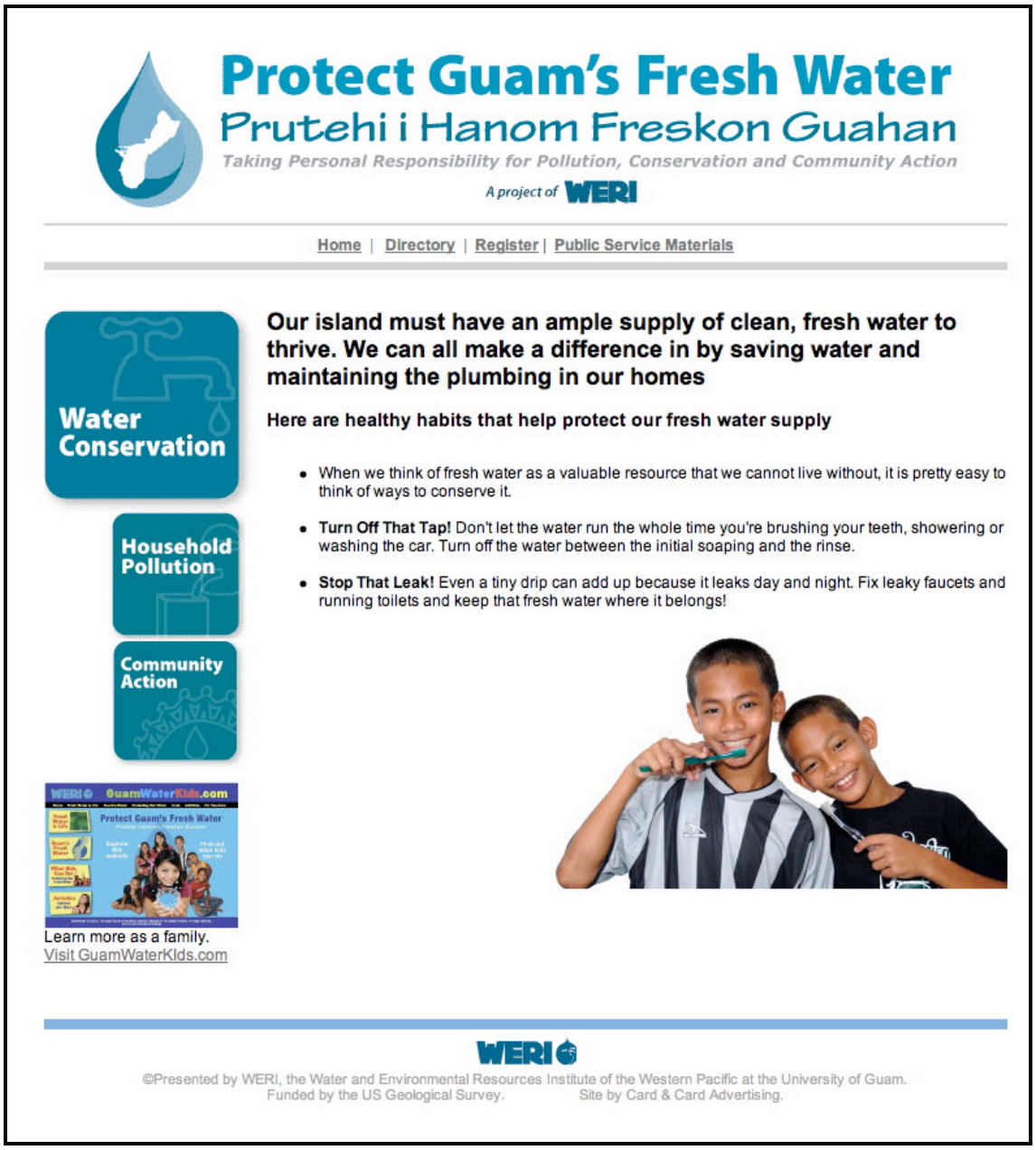


Figure 4. Water Conservation Information web page

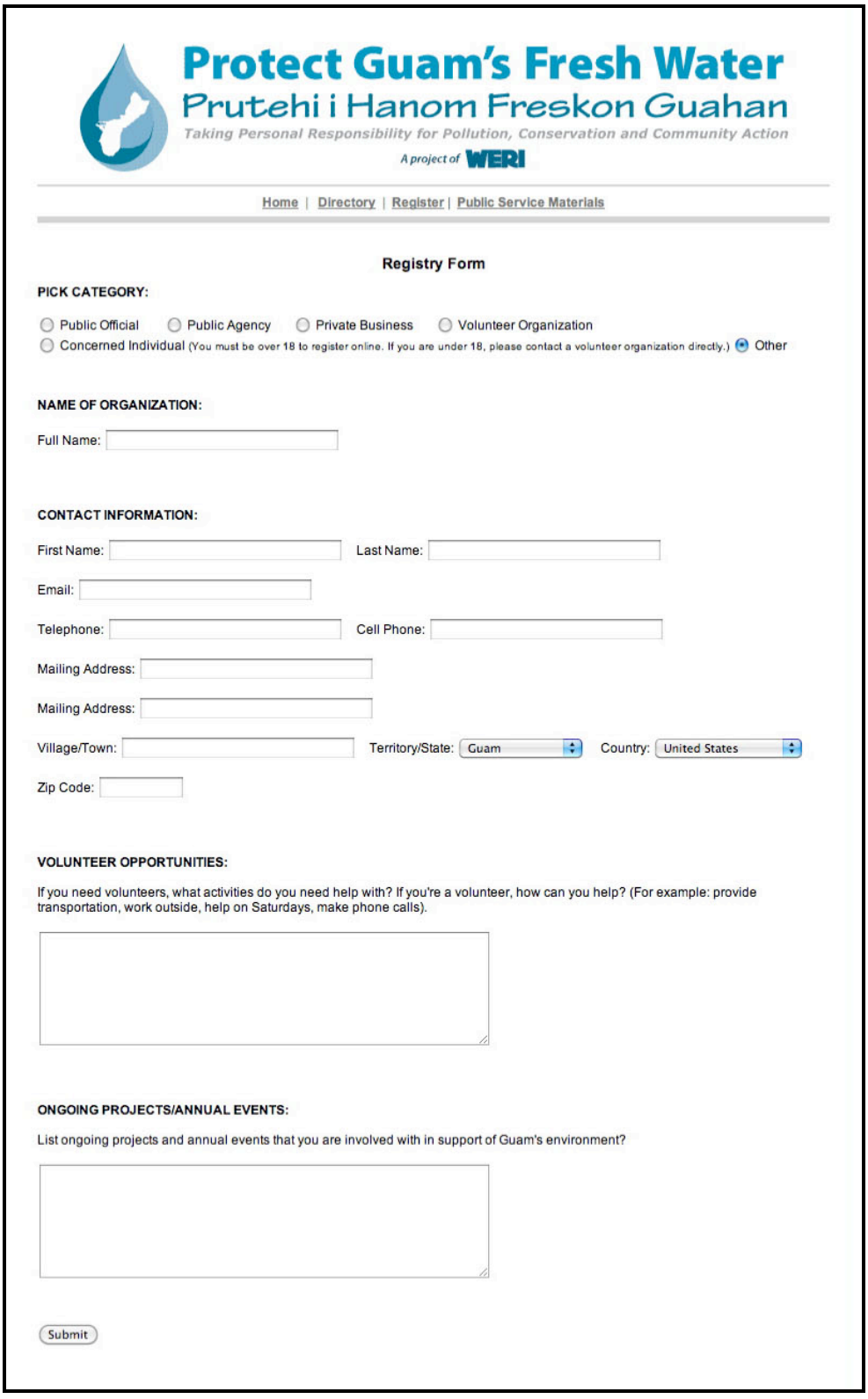
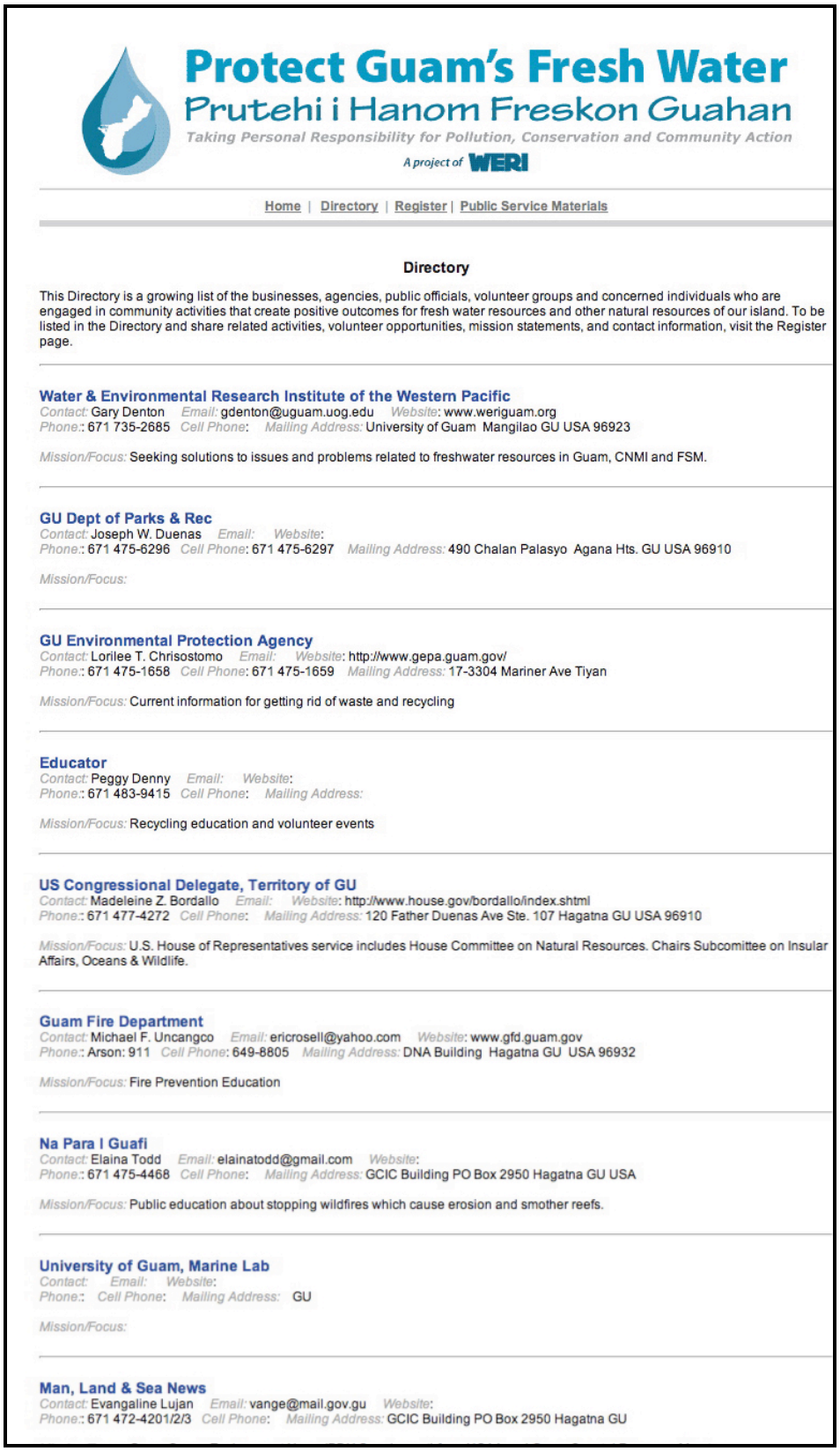


Figure 5. Registry Page



Protect Guam's Fresh Water

Prutehi i Hanom Freskon Guahan

Taking Personal Responsibility for Pollution, Conservation and Community Action

A project of WERI

Home | Directory | Register | Public Service Materials

Directory

This Directory is a growing list of the businesses, agencies, public officials, volunteer groups and concerned individuals who are engaged in community activities that create positive outcomes for fresh water resources and other natural resources of our island. To be listed in the Directory and share related activities, volunteer opportunities, mission statements, and contact information, visit the Register page.

Water & Environmental Research Institute of the Western Pacific
Contact: Gary Denton *Email:* gdenton@uguam.uog.edu *Website*: www.weriguam.org
Phone:: 671 735-2685 *Cell Phone*: *Mailing Address:* University of Guam Mangilao GU USA 96923

Mission/Focus: Seeking solutions to issues and problems related to freshwater resources in Guam, CNMI and FSM.

GU Dept of Parks & Rec
Contact: Joseph W. Duenas *Email:* *Website*:
Phone:: 671 475-6296 *Cell Phone*: 671 475-6297 *Mailing Address:* 490 Chalan Palasyo Agana Hts. GU USA 96910

Mission/Focus:

GU Environmental Protection Agency
Contact: Lorilee T. Chrisostomo *Email:* *Website*: http://www.gepa.guam.gov/
Phone:: 671 475-1658 *Cell Phone*: 671 475-1659 *Mailing Address:* 17-3304 Mariner Ave Tiyan

Mission/Focus: Current information for getting rid of waste and recycling

Educator
Contact: Peggy Denny *Email:* *Website*:
Phone:: 671 483-9415 *Cell Phone*: *Mailing Address:*

Mission/Focus: Recycling education and volunteer events

US Congressional Delegate, Territory of GU
Contact: Madeleine Z. Bordallo *Email:* *Website*: http://www.house.gov/bordallo/index.shtml
Phone:: 671 477-4272 *Cell Phone*: *Mailing Address:* 120 Father Duenas Ave Ste. 107 Hagatna GU USA 96910

Mission/Focus: U.S. House of Representatives service includes House Committee on Natural Resources. Chairs Subcomittee on Insular Affairs, Oceans & Wildlife.

Guam Fire Department
Contact: Michael F. Uncangco *Email:* ericrosell@yahoo.com *Website*: www.gfd.guam.gov
Phone:: Arson: 911 *Cell Phone*: 649-8805 *Mailing Address:* DNA Building Hagatna GU USA 96932

Mission/Focus: Fire Prevention Education

Na Para I Guafi
Contact: Elaina Todd *Email:* elainatodd@gmail.com *Website*:
Phone:: 671 475-4468 *Cell Phone*: *Mailing Address:* GCIC Building PO Box 2950 Hagatna GU USA

Mission/Focus: Public education about stopping wildfires which cause erosion and smother reefs.

University of Guam, Marine Lab
Contact: *Email:* *Website*:
Phone:: *Cell Phone*: *Mailing Address:* GU

Mission/Focus:

Man, Land & Sea News
Contact: Evangaline Lujan *Email:* vange@mail.gov.gu *Website*:
Phone:: 671 472-4201/2/3 *Cell Phone*: *Mailing Address:* GCIC Building PO Box 2950 Hagatna GU

Figure 6. Directory Page

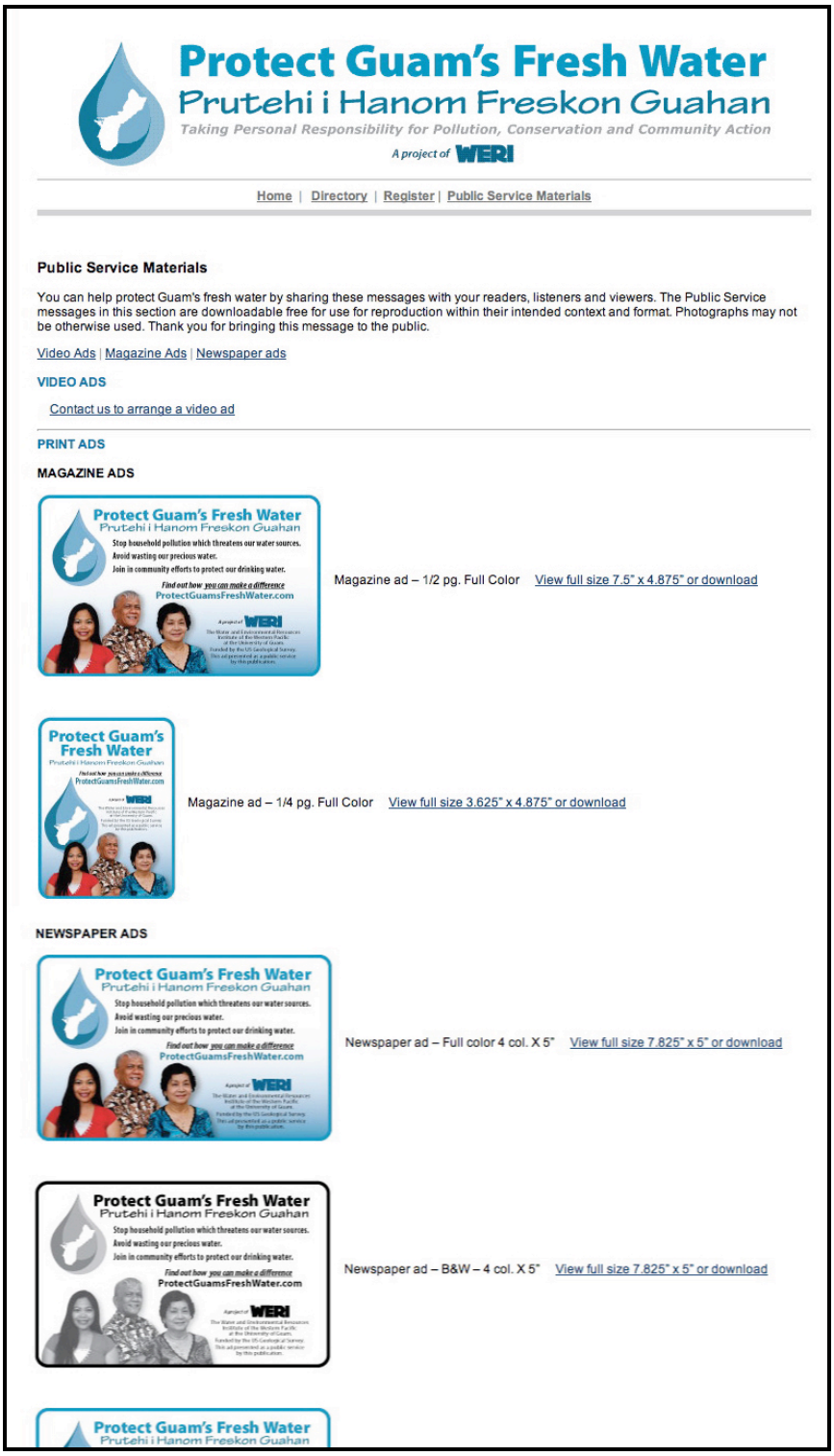


Figure 7. Public Service Materials webpage

(end)

Atoll Water Budget Modeling, Information Transfer and Training for the Federated States of Micronesia

Basic Information

Title:	Atoll Water Budget Modeling, Information Transfer and Training for the Federated States of Micronesia
Project Number:	2009GU163B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	Atoll island aquifers
Principal Investigators:	John Jenson

Publication

1. Bailey, Ryan T., John W. Jenson, and Arne E. Olsen, 2010, Estimating the Ground Water Resources on Atoll Islands, Water, v. 2, p. 1-27, doi:10.3390/w2010001

PROJECT SYNOPSIS REPORT

Project Title: Atoll Water Budget Modeling, Information Transfer and Training for the Federated States of Micronesia

Problem and Research Objectives

The shallow depths between the land surface and the water table as well as between the water table and underlying freshwater-seawater interface make atoll island aquifers uniquely vulnerable to contamination. Thinning of the lens during long droughts can make the freshwater lens especially vulnerable. Moreover, flooding of the island by sea water not can displace many or all of the residents and ruin crops and infrastructure, but may leave the shallow aquifers contaminated with salt water even after residents could otherwise return and resume normal activity.

In response to the interests expressed by island residents and FSM officials, WERI researchers have developed an atoll aquifer model for the Caroline Islands (Bailey et al., 2008a). The model runs on lap-top or notebook computers, with a published WERI technical report (#120) that serves as an operator's manual for the model (Bailey et al., 2008a) and another (#119) that serves as an educational text on atoll island hydrology and modeling (Bailey et al., 2008b). The technical reports are available on CD and on-line on the WERI website (www.weriguam.org/v2 /index.php). WERI instructors use the technical reports, along with supporting PowerPoint presentations to deliver lectures on the basic aspects of atoll hydrology and conduct hands-on training on the use of the model. These sessions can be readily set up and conducted in any classroom equipped with electricity and a projection screen or suitable wall. There is now an ongoing need to train the designated end-users in government agencies and educational institutions of the FSM on how to operate the model to apply its results to water resource management problems.

Methodology

An initial orientation to the model was conducted by WERI researchers during April and May 2008, when they traveled to Yap, Chuuk, and Pohnpei to deliver copies of the model and supporting technical reports (Bailey et al., 2008a; Bailey et al., 2008b) to agency heads and policy makers who supported the project. During August of the 2009 (the period of this report) the research team made follow-up visits to conduct a series of workshops for FSM state water resources agencies on Yap and Pohnpei.

Principal Findings and Significance

The training on the models enables FSM water resources managers and planners to use the model to make more reliable policies and plans to build and support sustainable communities on the atoll islands of the FSM. Improving water resources availability and sustainability on small island communities promotes economic and social stability, as well as preserving the preferred way of life for many current and future residents of the FSM. The training has been so well received that WERI has committed to continue offering it an annual basis for the time being.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	6	0	0	0	6
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	8	0	0	0	8

Notable Awards and Achievements

For the second year in a row, WERI conducted the highly popular Groundwater Resources Management Training Course specifically for the inhabitants of island atolls in the FSM. This year the course was conducted in Pohnpei and Yap, and once again attracted island leaders and government officials. Participants were trained in the use of a high-resolution computer model of an idealized atoll aquifer to predict the sustainable management of their groundwater resources under various climatic scenarios. The training was so well received that WERI has currently committed to offering additional workshops on an annual basis, at least, for the time being.

The WERI Pollution Monitoring and Assessment Program underway in Saipan continues to expose hitherto unknown areas of heavy metal contamination associated with past land use activities. Relatively high mercury levels in fish from the middle reaches of Saipan Lagoon, for example, were successful traced back to an old incinerator site at the local hospital about 1 km in land. Storm water runoff from the hospital grounds was responsible for transporting the mercury from the incineration site to the coast via a network of drainage channels. This year the program identified a lead ‘hot spot’ at the southern end of the lagoon. Sedimentary lead concentrations exceeded threshold levels for adverse biological effects and resident bivalves in the area were deemed unfit for human consumption. The Saipan Division of Public Health and the Division of Environment Quality were alerted and are planning to post health advisories in the area.

WERI faculty continues to engage both graduate and undergraduate students in their research activities. This year we are pleased to announce that WERI student, Ms. Theresa Datuin, graduated from the Environmental Science MS Program with distinction. Nathan’s thesis project, entitled A Time-Series Analysis on the Responses of the Northern Guam Lens Aquifer to Variations of Rainfall Events. This research provides vital information on fundamental processes and properties of the northern Guam lens aquifer. Such information is essential for the successful calibration and validation of any future numerical modeling attempts to determine aquifer sustainability.

Publications from Prior Years

1. 1991GU02B ("Manganese in Watershed Environments of Southern Guam: Part I, Baseline Study of Sources, Sinks and Speciation") - Articles in Refereed Scientific Journals - Denton, Gary R.W., H. Galt Siegrist, Jean P. Jano-Edwards, 2009, Trace Elements in Pandanus (Pandanus tectorius) from a Manganese-Enriched Wetland in Southern Guam: A Possible Lytico-Bodig Connection? Journal of Toxicology and Environmental Health, Part A, 72: 1-3.
2. 1991GU02B ("Manganese in Watershed Environments of Southern Guam: Part I, Baseline Study of Sources, Sinks and Speciation") - Articles in Refereed Scientific Journals - Wilson, Robert, Brian Pyatt, and Gary R.W. Denton, 2009, An Evaluation of the Bioavailability and Bioaccumulation of Selected Metals Occurring in a Wetland Area on the Volcanic Island of Guam, Western Pacific Ocean, Journal of Environmental Sciences, 21: 1-5.
3. 1991GU02B ("Manganese in Watershed Environments of Southern Guam: Part I, Baseline Study of Sources, Sinks and Speciation") - Conference Proceedings - Denton, Gary R.W., H. Galt Siegrist, and Jean P. Jano-Edwards, 2009, Metal Deficiencies and Imbalances in Wetland Plants from a Manganese-Enriched Wetland in Southern Guam: A Preliminary Investigation. Progress in Environmental Sciences and Technology, Vol. II Part B: 1853-1858.
4. 1999GUC-09 ("Island Karst Hydrology of Guam and Its Incorporation into a General Carbonate Island Karst Model") - Conference Proceedings - Taborosi, Danko, John W. Jenson, John M.U. Jocson and John E. Mylroie, 2009, Coastal discharge features from an uplifted carbonate island aquifer: Northern Guam, Mariana Islands, in White, W. B., ed., Proceedings of the 15th International Congress of Speleology, National Speleological Society, Kerville, Texas, July 19-25, v. 2, p. 548-553.
5. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Conference Proceedings - Stafford, Kevin, W., John W. Jenson, and John E. Mylroie, 2009, Eogenetic karst of the carbonate islands of the Northern Marianas, in White, W. B., ed., Proceedings of the 15th International Congress of Speleology, National Speleological Society, Kerville, Texas, July 19-25, v. 2, p. 542-547.
6. 2003GU22B ("Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer Outfalls") - Articles in Refereed Scientific Journals - Denton, Gary R.W., R. John. Morrison, Brian G. Bearden, Peter Houk, and John A, Starmer, 2009, Impact of a Coastal Dump in a Tropical Lagoon on Trace Metal Levels in Surrounding Marine Biota: A Case Study from Saipan, Northern Mariana Islands (CNMI), Marine Pollution Bulletin, 58: 424-455.
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